AFRL-HE-WP-TR-2007-0048

Crowd Modeling in Military Simulations: Requirements Analysis, Survey, and Design Study

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April 2003

Interim Report for April 2002 – April 2003

Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7604

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AFRL-HE-WP-TR-2007-0048

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
April 2003	Interim	April 2002 - April 2003

4. TITLE AND SUBTITLE
Crowd Modeling in Military Simulations: Requirements Analysis, Survey, and Design Study

5a. CONTRACT NUMBER N00140-97-D-2051

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER 63832D

6. AUTHOR(S)
Mikel D. Petty, Ryland C. Gaskins, Frederic D. McKenzie

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER 0476DM00

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Virginia Modeling, Analysis & Simulation Center
Old Dominion University
Norfolk VA 23529-0099

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7604

Defense Modeling and Simulation Office
1901 N. Beauregard Street, Suite 500
Alexandria VA 22311-1705

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECS, DMSO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-WP-TR-2007-0048

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.
AFRL/PA cleared on 02 July 2007, AFRL-WS-07-1554.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report provides a comprehensive requirements analysis, literature survey, and engineering design study of crowd modeling in military simulations. This report has five main sections. An introductory section is followed by a brief overview of the research effort, with descriptions of the project motivation, history, and methodology. An analysis of requirements for crowd modeling in military simulations is detailed. Following that, a survey of the state of the art in psychological and computational models of crowd behavior is presented. Then a design study of a crowd simulation federate, which is based in part on a set of implementation experiments, is reported. Finally, a statement of findings and recommended research concludes the primary content of the report. The appendices of this report include a list of references, a list of acronyms and abbreviations, a partial list of sources for the requirements analysis process, and brief biographies of the authors.

15. SUBJECT TERMS Crowd Modeling, Human Behavior Modeling, Crowd Modeling Literature Survey, Crowd Simulation Federate

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** John L. Camp
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	72	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

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1. Executive Summary

Crowds of non-combatants play a large and increasing role in modern military operations, and often create substantial difficulties for the combatant forces involved. In spite of this, models of crowds and crowd behavior are essentially absent from current production military simulations. The absence of models of crowds in military simulation, and the need to include them, has been widely recognized.

An adapted form of a previously proposed requirements analysis method was applied to identify crowd modeling requirements and relate them to intended uses of military simulation. A large number of crowd modeling requirements were found; those requirements were expressed in various forms, including crowd behaviors needed, military missions affected by crowds, and crowd effects to model. The identified requirements provide a good basis for implementing a useful crowd simulation. The primary finding of the requirements analysis was that because of the requirements' diversity in scope and intent no single crowd behavior model is likely to satisfy all of the requirements.

There are many variables that may influence crowd behavior. Few existing models of crowd behavior have strong underpinnings in psychology. An improved understanding of cognitive psychology, including better connection of cognition to behavior, is essential to provide a psychological basis for crowd models. Previous psychological research suggests that models of crowd behavior should consider crowd members' past experiences and expectations for future outcomes and that cultural differences can have an important influence on crowd behavior and should be modeled. Future research on crowd behavior during military operations should address these issues.

The risks inherent in the future implementation of a crowd federate in the areas of module integration and terrain correlation have been mitigated by implementing a crowd federate exploratory prototype and using it to conduct implementation experiments that identified possible problems and solutions. The usefulness of a modular software architecture with separate cognitive and physical models for crowd behavior, connected via a carefully designed interface, was established. A significant level of flexibility was found in commercial entertainment industry software tools. Those tools can reduce the difficulty of implementing portions of a crowd behavior simulation.

This study has led to the formulation of a number of focused research questions related to crowd simulation, including issues of crowd simulation architecture and behavior fidelity requirements. A research project is recommended to implement a crowd federate and experimentally address some of the open research questions.

2. Introduction

Introductory material about this report, including its purpose, its structure, and its authors are contained in this section.

2.1 Purpose

This report is a requirements analysis, literature survey, and engineering design study of crowd modeling in military simulations.

This report was prepared for the Defense Modeling and Simulation Office (DMSO) by the Virginia Modeling, Analysis and Simulation Center (VMASC) of Old Dominion University (ODU). It describes work done under and is the final report for contract N00140-97-D-2051, Delivery Order 0029, titled "Composable Reconfigurable Environments for Acquisition, Training, and Experimentation (CREATE)". The Old Dominion University Research Foundation project number is 273929.

2.2 Structure of this report

This report has five main sections. This introductory section is followed by a brief overview of the project, with descriptions of the project's motivation, history, and methodology. An analysis of requirements for crowd modeling in military simulations is detailed. Following that, a survey of the state of the art in psychological and computational models of crowd behavior is presented. Then a design study of a crowd simulation federate, which is based in part on a set of implementation experiments, is reported. Finally, a statement of findings and recommended research concludes the primary content of the report.

The appendices include a list of references, a list of acronyms and abbreviations, a partial list of sources for the requirements analysis process, and brief biographies of the authors.

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2.4 Acknowledgements

This research was sponsored by the Defense Modeling and Simulation Office and primarily supervised by Michael J. Young, Ph.D. and John G. Tyler, Ph.D. That support is gratefully acknowledged. The authors also thank the experts who provided input during the requirements analysis process. Old Dominion University students Taimur Khan and Qingwen Xu contributed to the project.

3. Project overview

This section describes the project's motivation, history, and methodology.

3.1 Project motivation and goals

Crowds of non-combatants play a large and increasing role in modern military operations, and often create substantial difficulties for the combatant forces involved.

> "In Somalia, U. S. Marines often faced hostile crowds of rock-throwing women and children. In Bosnia, U. S. Army soldiers had to disperse angry mobs of Serb hard-liners near the town of Banja Luka. More recently, Danish, French, and Italian forces attempted to control riots between ethnic Albanians and Serbs in Mitrovice, Albania." [Kenny, 2002]

> "All military operations, large or small, have a crowd control/crowd confusion factor. … [C]rowds are one of the worst situations you can encounter. There is mass confusion; loss of control and communication with subordinates; potential for shooting innocent civilians, or being shot at by hostiles in the crowd; potential for an incident at the tactical level to influence operations and policy at the strategic level." [Ferguson, 2003]

In spite of the military challenges and risks imposed by crowds, models of crowds are essentially absent from current production military simulations. This omission has been understandable in the context of legacy simulations that were historically focused on large-scale engagements between heavy mechanized forces in primarily non-urban settings. However, in the last decade the threat has changed and future engagements are expected to often involve lighter forces in urban settings. In simulations of such scenarios the absence of crowds and of non-combatants in general is a more serious departure from realism. The absence of models of crowds in military simulation, and the need to include them, has been widely recognized:

> "Military forces are increasingly called upon to support operations other than war in which they come into contact with civilian populations. In some cases, the interaction takes place with crowds of civilians. Unfortunately, the computer generated forces that support virtual training systems do not yet support the simulation of crowds of civilians." [Reece, 2002]

> "Representations are needed for … (neutrals or civilians) to represent operations other than war and the interactions among these forces." [Pew, 1998].

> "With the Army's growing emphasis on low-intensity conflicts and operations other than war, the need to consider the civilians that live in the environment in which our forces will operate has become increasingly important. … [C]ivilian populations can have a profound affect in a crowded battle space. … There is, however, little representation of the civilians in today's military simulations." [Fields, 2000]

> "[T]he ability to represent the behavior of crowds is currently lacking in military modeling and simulation technique." [DAF, 2003]

Figure 1 and Figure 2. U. S. forces confront a crowd of protesters in Baghdad (photos: AP).

This project was motivated by a need to address the absence of crowd models from military simulation. The project's overarching goal was to perform necessary preparatory work prerequisite to the successful implementation of a useful crowd simulation capability. The project had three specific goals:

1. Identify and analyze requirements for crowd modeling in military simulation.
2. Examine existing models, simulations, and research relevant to crowd modeling.
3. Develop an understanding of design considerations for a crowd simulation.

3.2 Project history

The project officially started July 8, 2002 and officially ended March 31, 2003. During the project the goals, tasks, and methodology changed in response to an understanding of the state of crowd modeling in the military simulation context that developed over time. In this section we briefly recount the project history with emphasis on that change.

Initially, the overall objectives of this project were as follows:

1. Evaluate the state of the art of composable simulation by the use of a reconfigurable experimentation environment to conduct human performance experiments.
2. Conduct the human performance experiments to establish and validate a proposed requirements definition process and determine requirements across several domain applications.

To accomplish those initial objectives, the project had three tasks:

1. Develop an experimental Composable Reconfigurable Environment for Acquisition Training, and Experimentation (CREATE). Design the CREATE environment based on a requirements analysis process. Demonstrate that the CREATE environment is suitable for human performance experiments.
2. Develop a modification plan to the CREATE environment based on experimental results.
3. Conduct a demonstration of the CREATE environment to show suitability for future human performance experiments.

During the period July 8, 2002 to September 30, 2002 representatives of DMSO, VMASC, the University of Pennsylvania, the Institute for Creative Technologies, the U. S. Joint Forces Command (JFCOM), and other interested organizations were involved in a continuing attempt to refine the scope and emphasis of the overall research program, of which the CREATE project was only a part, and to specify how the work being done by each participating institution would fit together. To that end, multiple project planning meetings and technical interchanges were conducted. During these events many important project ideas, including the overall project concept, research activity integration schemes, technical architectures, and experimental scenarios were extensively discussed and frequently revised.

On October 1, 2002 it was determined by consensus of DMSO and VMASC that the difficulties encountered in project definition during the first three months of the project period were due, in large part, to an incomplete understanding of the requirements for crowd modeling in military simulation. In response to that realization VMASC's project goals and tasks were substantially reformulated. DMSO and VMASC agreed that the reformulated goals and tasks were consistent in intent with the earlier items. The reformulated goals were those listed in the previous section:

1. Identify and analyze requirements for crowd modeling in military simulation.
2. Examine existing models, simulations, and research relevant to crowd modeling.
3. Develop an understanding of design considerations for a crowd simulation.

The reformulated tasks closely paralleled the goals:

1. *Requirements analysis.* Conduct a requirements analysis to identify and analyze crowd modeling requirements in military simulation, using a proposed methodology.
2. *State-of-the-art survey.* Survey past and current psychology research in the area of crowd modeling, as well as existing models and simulations of potential applicability. Evaluate their relevance and assess their utility and maturity, looking forward to possibly future implementation of a crowd simulation capability.
3. *Design study.* Develop concepts of the design of a crowd federate, i.e., a simulation of crowd behavior that can operate in a distributed simulation system. Experimentally test aspects of the design that are considered central and/or potentially problematic in implementing such a simulation.

After October 1, 2002 VMASC activities focused on the reformulated goals and tasks.

3.3 Project methodology

The general methodology used and some of the important specific activities performed by VMASC to meet the reformulated goals are described in this section.

Requirements analysis. VMASC consulted with M&S users in the joint community (and others) regarding their current and anticipated needs for crowd modeling in joint simulations. VMASC also surveyed published sources calling for crowd modeling. VMASC used an adaptation of a methodology previously proposed for human behavior modeling requirements analyses [Chandrasekaran, 1999]. That methodology calls for a series of case studies, using task analysis techniques, to establish the relationship between simulation use requirements and cognitive model fidelity/capability requirements. Each case study is to be focused on a different cognitive modeling topic. The CREATE requirements analysis was essentially one of the case studies, focused on crowd modeling, with adaptations to the methodology to specialize it for the crowd modeling domain.

The original methodology, this project's adaptation of it, and the results of the requirements analysis are presented in section 4 of this report.

State-of-the-art survey. VMASC conducted a survey of the current state-of-the-art in crowd modeling, from two perspectives. The first perspective was psychological; here VMASC surveyed the psychological research literature for research relevant to understanding and modeling the behavior of crowds. Special attention was given to research that considered crowd behavior in military scenarios, but other scenarios, including civil unrest and sporting event riots were also considered. Over 50 references for both descriptive (qualitative) and predictive (quantitative) models associated with crowd modeling were studied. Examination of the literature found research of some relevance, though it was not often focused on military scenarios.

The second perspective was engineering; here VMASC identified models and simulations with capabilities relevant to crowd modeling that have been or are being implemented as computer systems. Both models of crowd cognitive behavior and crowd physical behavior were of interest. VMASC assessed the capabilities of those systems.

The results of the survey are given in section 5 of this report.

Design study. VMASC developed concepts of a design for a crowd federate. The design study included consideration of details the crowd federate's input and output, software architecture, essential algorithms, and data assumptions.

VMASC designed multiple notional crowd federation architectures to address the evolving project and scenario concepts. VMASC researchers reviewed existing software and simulations with capabilities related to crowd modeling, including AI.implant, DISAF, JSAF, JCATS (Figure 3), and Clutter. Versions of some of this software were acquired and installed at the VMASC laboratory.[1] Aspects of the evolving design were implemented and tested experimentally to confirm (or refute) the design concepts.

The results of the design study and associated experiments are reported in section 6 of this report.

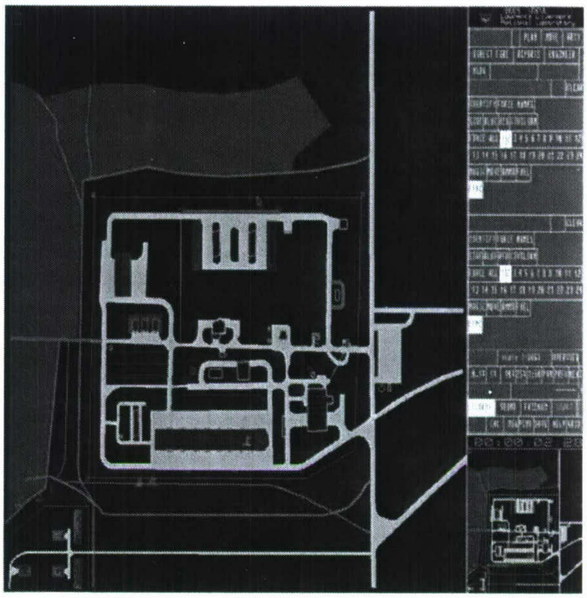

Figure 3. Sample JCATS screen image.

[1] The JCATS system seemed to be of significant potential relevance to the project, both as a combat simulation to provide the military scenario context for crowd behavior and as a possible host system in which to implement new crowd behavior capabilities. Because of this potential, attempts were made by VMASC through contacts at both the Lawrence Livermore National Laboratory (LLNL) and JFCOM to secure access to the source code for the JCATS simulation for use and experiment. Despite significant efforts, this attempt was ultimately unsuccessful; access to the source code was denied.

4. Crowd simulation requirements analysis

This section details an analysis conducted to identify and organize the requirements for crowd modeling capabilities in military simulation. First, the methodology used for the requirements analysis is explained. Following that, the requirements identified are listed and discussed. Finally, summary findings of the analysis are given.

4.1 Introduction

Chandrasekaran and Josephson explain guiding principles and propose a method for performing requirements analysis in the domain of human behavior modeling [Chandrasekaran, 1999]. These ideas are directly relevant to the process of establishing requirements for crowd modeling in military simulation. Their two main points are:

1. The intended uses or purpose of a simulation should determine its fidelity requirements; arbitrarily pursuing more fidelity, or as much fidelity as possible, without having a basis in requirements is unjustifiable.
2. A "strategy" (i.e., a method) based on purpose-driven task analysis is a recommended means for "empirically investigating" and determining the requirements, both fidelity and capability, for cognitive models.

They describe the recommended requirements analysis strategy and argue that it should be applied in a set of studies to determine the fidelity requirements for human behavior modeling:

> "... case studies should be performed to analyze the actual requirements for cognitive models in real-world examples of military uses of simulation." [Chandrasekharan, 1999]

Though the need for crowd modeling in military simulation has been recognized, it is not clear how much fidelity the models must have to be effective. From a training perspective, psychological research is necessary to assess its effect on training and human performance and to identify its important instructional aspects. Possible variables for consideration in such research include crowd behavior fidelity, skill levels necessary for optimal training performance validity, and cognitive models most representative of crowd behavior in military scenarios. Further analysis of the simulation could also yield useful research information in the area of situation awareness and tactical decision-making under stress, training technology, and human behavioral representation techniques. From an experimental perspective, the effect that different levels of crowd behavior fidelity have on scenario outcome is of interest. Similarly considerations apply to analysis and acquisition applications.

There is a widespread tendency to assume that more fidelity in models is better for a simulation. For example, in the case of crowd modeling in an individual level simulation, it might be assumed that simulated crowd members must have realistic bodies, emotional states, and distinct personalities, and complex behavior repertoires, based on sophisticated cognitive models. However, assumptions like this may be an oversimplification if the purposes of the simulation are not considered, as Chandrasekharan and Josephson assert:

> "We argue that the pursuit of high fidelity cognitive models, unfettered by detailed considerations of what we want the models for, is so unfocused as to be almost useless for practical purposes. No cognitive model can be detailed enough, in every respect, to serve for every purpose we might conceivably use it for, and not practical purpose is such that an unbounded degree of fidelity is significantly useful for its practical achievement. We argue that what a cognitive model needs to contain is vitally affected by what kinds of questions one wishes to answer, i.e., the goals of the simulation." [Chandrasekharan, 1999]

There are possible counter-arguments to their first point, i.e., that pursuing fidelity beyond requirements are unjustifiable. For example, additional fidelity beyond that strictly required by the initial requirements may allow a cognitive model to support later emerging requirements that were initially unanticipated. Nevertheless, the argument that fidelity should be tied to requirements is convincing. As for their second point, that determining human behavior modeling requirements requires methodical analysis, we see the requirements analysis reported here and the behavior fidelity experiment later proposed as future work as examples of such studies.

4.2 Requirements analysis process

We first analyze the method of Chandrasekharan and Josephson and then explain how it was adapted for the crowd modeling requirements analysis. In the list that follows, the numbered items are the steps of the method as given by Chandrasekharan and Josephson [Chandrasekharan, 1999]; they are followed by commentary regarding the steps:

1. *Conduct a set of case studies wherein concrete examples of military uses of the simulation are studied empirically.*

   Note that "uses" of simulation are studied. The basic idea of the method is that simulation requirements follow from simulation uses. However, the general term "simulation use" has several possible interpretations. It could arguably refer to broad categories of simulation applications, e.g., training or analysis; narrow subapplications within those broad applications, e.g., command staff training or doctrine development; generic use cases, e.g., training a company commander for situations where the opposing side adopts a certain tactic (this example is from [Chandrasekharan, 1999]); or specific use events, e.g., the Unified Endeavor 03-1 exercise or the Millennium Challenge 02 experiment.

2. *For each case, analyze the demands on simulated entities and characterize these demands relative to the purposes for which the simulation is conducted.*

   "Simulated entities" does not necessarily mean automated or computer controlled; there may have been a need for entity behaviors that was met via role-player control. "The purposes for which a simulation was conducted" suggests that the answer to the question in step 1 is specific use event.

3. *Map out the tasks to be performed, both by the simulation user and by simulated agents, in terms of goals and subgoals.*

   To understand this step, it is necessary to first clarify what is meant by "tasks" and "goals and subgoals". Considering tasks first, Chandrasekharan and Josephson explain that there are two types of tasks in a simulation use, the tasks of the simulation users and the tasks of the simulated entities[2]. The tasks for simulation users are interpreted as those actions they

[2] Chandrasekharan and Josephson [Chandrasekharan, 1999] use the term "agents" to refer to the simulated people and groups of people that are performing cognitive tasks in the simulation. We avoid that term because it also has a separate and widely used meaning as a software organization technique [Weiss, 1999] [Wooldridge, 2002]. Although simulated agents may be implemented using software agents, the two are distinct concepts. Software

may perform while using the simulation, such as constructing a scenario or commanding a force. The tasks for simulated entities are interpreted as their run-time behaviors. Run-time behaviors of simulated entities include both scenario-specific actions (e.g., capture Basra) and domain-generic behaviors (e.g., conduct hasty attack). Generic behaviors are more likely to be relevant to understanding general requirements for behavior modeling. As for goals, they give an example that makes clear that here the "goals" are the users' intended purposes for the simulation (e.g., training), and not the objectives of the simulated entities' behaviors in the simulation (e.g., capture the bridge).[3]

Note that in the previous step the question was "demands" on simulated entities, whereas in this step, the concern is the "tasks" to be performed. This is understood to mean that the demands on the simulated entities are expressed in terms of tasks for them to perform, and that those tasks are interpreted as run-time behaviors, which must be performed at some sufficient level of fidelity. Hence the set of demands on simulated entities imply a repertoire of run-time behaviors they must be capable of exhibiting, and some indication of the level of fidelity those behaviors should have. Those behaviors and their associated fidelity levels together express the requirements the Chandrasekharan and Josephson is designed to elicit.

4. *Develop concepts and vocabulary for describing these task structures and for characterizing the similarities and differences among the different uses of simulation.*

   In this case, "different uses" may make more sense in terms of application areas or levels of warfare. A behavior such as "conduct deliberate attack" would have different requirements and implementations for different areas and/or different levels. As for "concepts and vocabulary", we will rely on the existing concepts and terms for application areas and levels of warfare to identify simulation uses[4] and on behavior names to identify "task structures". Of course, unlike military behaviors where behavior names are doctrinally defined and widely understood, crowd behaviors are not so clear. Some terminology for crowds can be drawn from the psychological literature, but there is some variance in those sources. The need to develop vocabulary exists.

5. *Seek generalizations that aid description and analysis and help to predict the characteristics of further examples.*

   The "generalizations" may be findings that certain types of behaviors, at certain fidelity levels, are needed for simulation uses in certain application areas and/or at certain levels of warfare. To apply this method to crowd modeling, it would be useful to identify simulation uses, either use events or use categories, where crowd modeling was present or was needed, and to produce generalizations by examining those uses.

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agents can be used to implement processes other than simulated agents and simulated agents need not be implemented using software agents. To reduce the potential for confusion, we use the term "entities" instead.

[3] Even though Chandrasekharan and Josephson say "goal", we will generally use the terms "purpose" or "intended uses", rather than "goal", to denote the intended uses for a simulation. We do so because the latter term has a secondary connotation of entity behavior goal that the other terms do not have and is not relevant here.

[4] This will be detailed later.

To repeat, the fundamental idea of the Chandrasekharan and Josephson method is that a simulation's requirements follow from its intended uses or purpose. That idea is evident in their summarization of the method:

> "The kind of case study we are proposing is aimed as identifying the requirements on agent behaviors, whether or not the agents are to be humans to CGFs. In each study, analysis would identify which entities need to be modeled for achieving the simulation goals, what kinds of information each entity needs, what kinds of behavior and information each entity produces, and what kinds and degrees of fidelity are needed." [Chandrasekaran, 1999]

We distill the Chandrasekharan and Josephson method still further into these logical steps (here the symbol "→" means "determines"):

1. Purpose → Entity types required
2. Purpose and entity type → Cognitive tasks (Behaviors) required
3. Purpose and Cognitive task (Behavior) → Fidelity required

Clearly, the starting point for the method, and for an analysis that uses it, is the simulation's purpose. But there are multiple ways to categorize and characterize simulation purpose. Again, the possible types of simulation use are:

1. Broad application areas
2. Narrow subapplication areas
3. Generic use cases
4. Specific use events

These different types of simulation use are related in this way: broad application areas may be partitioned into narrow subapplication areas; narrow subapplication areas may be defined as sets of generic use cases; and generic use cases may be instantiated and executed as specific use events. (For brevity, the four types will be referred to without the adjectives, i.e., as application areas, subapplication areas, use cases, and use events.)

Two questions arise. First, which of these simulation use types is most appropriate for requirements analysis for human behavior modeling, in general? Second, which of these simulation use types is most appropriate for requirements analysis of crowd modeling in military simulation, in particular? The answer to the first question seems to be specific use events, according to Chandrasekharan and Josephson; for example, they write "… study real instances of uses of simulation …" [Chandrasekharan, 1999]. However, as already noted, examples of the method are given using the generic use case type. In any case, the first question need not be answered here, as this study is concerned with the second question.

For the purposes of analyzing the requirements for crowd modeling in military simulation, simulation use categories are defined (for brevity, "use categories") using two orthogonal dimensions: application area and warfare level.[5] Using application area to define simulation use type is relatively intuitive. Warfare level was used as well because, as will be seen, it was found to make an important difference in the requirements for crowd modeling.[6] The possible

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[5] The application areas used were training, analysis, experimentation, and acquisition. The warfare levels used were tactical, operational, and strategic. The application areas and warfare levels are defined in some detail in the next section.

[6] We initially intended to use level of resolution of simulated entity as the second dimension for defining simulation use categories. However, the simulation users consulted during the requirements analysis process preferred to

combinations of application area and warfare level were used to define the use categories considered in the requirements analysis. For each of the use categories, crowd modeling requirements generally applicable to that use category were identified. In addition, for some of the use categories, narrower use types (subapplication areas, use cases, or use events) were considered and their special crowd modeling requirements detailed as components or examples of their use categories. The crowd modeling requirements were defined primarily in terms of the crowd behaviors needed for each use category, though other requirements, such as crowd size and behavior fidelity, were also considered.

Use categories based on application area and warfare level are clearly broader than the use events or use cases that seem to be called for in the Chandrasekharan and Josephson method as the basis for requirements analysis. Conversely, in another respect this analysis of crowd modeling requirements is narrower than the case studies they describe. In their method, the case studies are intended to identify the full range of human behavior modeling requirements needed for a simulation use type. They advocate a broad analysis of a narrow simulation use type (a use case or use event). Our analysis of crowd modeling requirements starts from broad simulation uses (the use categories) but the analysis is narrow; the entity types and their control are given (crowds of non-combatants, controlled by software rather than human operators), rather than being determined during the analysis. The more specific focus on crowds balances the more general coverage of simulation use categories. The goal is to determine "what kinds of information each entity needs, what kinds of behavior and information each entity produces, and what kinds and degrees of fidelity are needed" for crowds in each use category.

With this in mind, we add an initial logical step to the method summary given before. In that additional step the simulation purpose for this analysis is determined from application area and warfare level. We call a combination of application area and warfare level a use category; each use category specifies a purpose, or more precisely, a class of simulation purposes. From those purposes entity types, cognitive tasks, and fidelity can be determined. However, in this analysis, attention is restricted to crowd entities. With the additional step and the restriction to crowd entities, the logical steps of the method become:

1. Use category (application area and warfare level) → Purpose
2. Purpose → Entity types required (crowd entities assumed)
3. Purpose and entity type (crowd entities assumed) → Cognitive tasks (behaviors) required
4. Purpose and Cognitive task (behavior) → Fidelity required

This approach is, we believe, an adaptation of the Chandrasekharan and Josephson method. Consider the points of the method in turn:

1. *Conduct a set of case studies.* This analysis of crowd modeling requirements is a single case study consistent in intent and closely related in method to those called for.
2. *Analyze the demands on simulated entities relative to simulation purpose.* The demands on crowds are analyzed for each of the use categories. The use categories represent the different classes of purposes typical for those use categories.

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express their requirements using level of warfare, so we adjusted our scheme. There is a rough mapping from level of warfare to level of resolution of simulated entity. At considerable risk of oversimplification, that mapping (using ground units for illustrative purposes) is tactical, individual to company; operational, company to corps; strategic, corps and above.

3. *Map out the tasks to be performed.* The tasks to be performed, given as run-time behaviors, are identified through reference to simulation users and research literature.
4. *Develop concepts and vocabulary.* For the most part the terminology used by simulation users and researchers, who identify the run-time behaviors with descriptive names, are applied. Inconsistent or overlapping behavior names are clarified.
5. *Seek generalizations.* Patterns of consistent required behaviors or fidelity levels for application areas or warfare levels are identified.

4.3 Application areas and warfare levels

Military simulations are used for a variety of purposes, and those purposes may be grouped or categorized in a variety of ways. For this analysis, those purposes grouped into four application areas: training, analysis, experimentation, and acquisition.[7] Each is defined in turn.

Training. Training simulations, in general, are intended to induce learning in human trainees who interact with or participate in the simulation. The trainees interact with or participate in the simulation, which provides an instructive experience. Flight simulators and command staff exercise drivers are well-known examples of training simulation; the former can teach aircraft control psychomotor skills via an immersive experience, while the latter can teach cognitive and decision-making skills by providing a realistic battlefield context.

Analysis. Analysis is the use of simulation to answer questions about some aspect of the system or scenario being simulated. Analysis is the use of simulation to answer questions about some aspect of the system or scenario being simulated. Military analysis simulations are often used to assess the effectiveness of new weapons systems, test new force structures, or develop doctrine. For example, simulation was used to conduct the experimental trials testing the design of a new naval surface combatant [Ewen, 2000]. In analysis applications simulation is used in a carefully controlled way, with run-to-run initialization differences restricted to the factors under question (e.g., different weapons performance levels). Repeatability, determinism, and the ability to isolate the cause of any particular observed effect are desirable characteristics of analysis simulation.

Experimentation. Experimentation is similar to analysis, in that the simulation is being used to answer questions, but in experimentation the questions are more open-ended and exploratory and "insights", rather than specific answers, are often the goal [Ceranowicz, 1999]. In experimentation, strict control of run-to-run outcome differences is less important than exploring in simulation a space of possibilities (e.g., a set of different operational concepts). The objective of such experimentation is "not to evaluate system effectiveness, but rather, to provide an environment and tools that will allow operators and analysts to discover new insights" [Ceranowicz, 1999]. Large simulation-based experiments have conducted by U. S. military

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[7] Chandrasekharan and Josephson identify these simulation "purposes", i.e., application areas in our terminology: "training, mission rehearsal, doctrine evaluation, and acquisition decisions" [Chandrasekharan, 1999]. We map their applications into those used here as follows: "training" and "mission rehearsal" are training; "doctrine evaluation" is analysis; and "acquisition decisions" is acquisition. They did not identify any purposes that map to experimentation. Another categorization of simulation purposes found, for example, in the OneSAF Operational Requirements Document has these application areas: Research, Development, and Acquisition (RDA), Advanced Concepts and Requirements (ACR), and Training, Exercise, and Military Operations (TEMO). We map these application areas into those used here as follows: RDA is analysis and acquisition; ACR is experimentation; and TEMO is training.

commands [Ceranowicz, 1999], notably including the recent Millennium Challenge 02 experiment.

Acquisition. Increasingly, simulation is being used to support acquisition.[8] In acquisition, the use of simulation can be broadly categorized into two general subapplication areas, colloquially described as "building the right thing" and "building the thing right" [Castro, 2002]. In the case of "building the right thing", simulations are used to compare or evaluate proposed or notional systems, combat or otherwise. The projected performance characteristics of those systems are stipulated and inserted into the simulation, where the effects a system with the given capabilities might have on mission outcomes are assessed in an analysis-like process. In the case of "building the thing right", simulation is used to support the system design and engineering process, at levels from individual components to integrated systems-of-systems. High-fidelity engineering simulations can be used to determine if a design will operate as intended [Castro, 2002].

Military simulations model operations at different levels of warfare, from tactical engagement simulations that model individual combatants to strategic theater simulations that model aggregate military units. Military simulation users are accustomed to specifying requirements for simulations in general by reference to those levels. Doctrinally, warfare is divided into three levels: strategic, operational, and tactical. Military operations at the different levels differ in important ways, including scale of forces involved, time duration, geographic scope, support and logistical requirements, and consequences. Although the boundaries between the levels can be fuzzy, and events may cut across the boundaries, the division is nevertheless useful; the levels are "doctrinal perspectives that clarify the links between strategic objectives and tactical actions" [DOD, 1995]. Quoting from an official joint doctrine manual, the warfare levels are defined as follows:

> "Strategic level of war – The level of war at which a nation, often as a member of a group of nations, determines national or multinational (alliance or coalition) security objectives and guidance, and develops and uses national resources to accomplish these objectives. Activities at this level establish national and multinational military objectives; sequence initiatives; define limits and assess risks for the use of military and other instruments of national power; develop global plans or theater war plans to achieve these objectives; and provide military forces and other capabilities in accordance with strategic plans." [DOD, 2001]
>
> "Operational level of war – The level of war at which campaigns and major operations are planned, conducted, and sustained to accomplish strategic objectives within theaters or operational areas. Activities at this level link tactics and strategy by establishing operational objectives needed to accomplish the strategic objectives, sequencing events to achieve the operational objectives, initiating actions, and applying resources to bring about and sustain these events. These activities imply a broader dimension of time or space than do tactics; they ensure the logistic and administrative support of tactical forces, and provide the means by which tactical successes are exploited to achieve strategic objectives." [DOD, 2001]
>
> "Tactical level of war – The level of war at which battles and engagements are planned and executed to accomplish military objectives assigned to tactical units or task forces. Activities at this level focus on the ordered arrangement and maneuver of combat elements in relation to each other and to the enemy to achieve combat objectives." [DOD, 2001]

As will be seen, for each combination of application area and warfare level, i.e., use category, different aspects of crowds and crowd behavior will be needed or emphasized. For example, in an immersive virtual environment used to train individual combatants at the tactical level,

[8] This application area is often called "simulation based acquisition" (SBA). Here the simulation-based aspect of the application is assumed.

simulated crowds of non-combatants could make target acquisition and selection more realistic by providing visual clutter and make mission decision making more challenging by adding the need to minimize non-combatant casualties. In an operational level simulation used for course of action analysis, the presence of crowds of refugees could make maneuver planning more accurate by slowing unit movement along road networks and through urban areas. Crowds can be important in any of the use categories, but the nature and degree of their importance, the behaviors that the crowd should be able to perform, and the fidelity needed in the crowd models, can vary by use category. The examples illustrate this; in a simulation of individual combatants, the actions and appearance of individual crowd members are important, while in an aggregate level simulation the outcome may depend on the cumulative effect of many crowd members.

4.4 Crowd modeling requirements lists

The crowd modeling requirements found were diverse in both content and form. There was a good consensus that crowds were needed in military simulation. For example:

> "The potential of this capability could provide a major benefit for many applications." [Ferguson, 2003]

However, there was less agreement on what the specific requirements were, and even less on how the requirements were expressed. The requirements, both as given by the users and drawn from published sources, were stated in several different ways. The first was in terms of needed crowd behaviors, e.g., "take hostile action against combatants", sometimes with a description of needed fidelity level. The second was in terms of military mission types for which crowds were generally needed, e.g., "urban warfare". The third was in terms of the effects that a crowd might have on a scenario that needed to be modeled, e.g., "road congestion". In the lists that follow, the entries remain true to the sources' responses and freely mix these types of requirements, fully aware that they are different types of requirements, or at least different ways of expressing requirements.[9]

Requirements that could be associated with a specific use category are listed first. In some cases, a requirement was given by a source as applicable to more than one specific use category; in those cases, the requirement is listed in each applicable use category. Following the lists of requirements by use category, more general statements of crowd modeling requirements are reported.

Training, tactical. For this use category, the specific crowd modeling requirements identified were as follows:

1. Tactical constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage") [Sokolowski, 2003] [OneSAF, 2001]. At the tactical level more detail and fidelity in crowd behavior is needed than at the operational level; in virtual simulations, detail and fidelity in crowd member appearance is also needed [Sokolowski, 2003].
2. Needed crowd size: ~100 persons [Sokolowski, 2003].
3. Needed crowd size: ~50-100 persons in a confined urban combat area [Ferguson, 2003].

[9] It is possible that deeper analysis of the military mission types or desired crowd effects would lead to the crowd behaviors needed to support those mission types. This is suggested by the method Chandrasekharan and Josephson [Chandrasekharan, 1999]. That deeper analysis will be pursued if we continue in this line of research.

4. Needed crowd size: ~5-10 persons for a small arms or aircrew tactical trainer [Ferguson, 2003].
5. Needed crowd size: "Somalia" [Bailey, 2003].
6. Urban warfare [Sokolowski, 2003] [Ferguson, 2003] [Bailey, 2003].
7. Noncombatant evacuation operations (NEO) [Sokolowski, 2003].
8. Military operations other than war (MOOTW) [Sokolowski, 2003] [Ferguson, 2003].
9. Homeland security operations [Sokolowski, 2003]; including crowd response to events such as natural disaster, terrorism, industrial accidents, disease epidemics [Ferguson, 2003].
10. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
11. Needed crowd behaviors: move randomly in scenario area, approach battle, flee battle, take hostile action against combatants (e.g., throw rocks), assist combatants (e.g., medical aid), conduct negotiations, ask for assistance, react to threats, react to directions concerning movement, riot to acquire food [Sokolowski, 2003]
12. Needed crowd behaviors: mass action to force combatant withdrawal, looting, provide human shield cover for combatants, mass action to overwhelm checkpoint security [Ferguson, 2003].
13. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].
14. Trafficability problems and road network congestion, especially at bridges and other choke points [Ferguson, 2003].
15. Displaced personnel requiring humanitarian assistance; such persons consume logistical supplies, requiring re-supply of food and water, and affect logistics of combat operations [Ferguson, 2003] [OneSAF, 2001].
16. Movement of non-combatant people and vehicles to provide "clutter" to obscure military movements for sensor platform operations [OneSAF, 2001] [Swaney, 2002] and for intelligence processes such as fusion, correlation, and targeting [Ferguson, 2003].
17. Crowd hysteria and confusion caused by misinformation or partial situational awareness [Ferguson, 2003].
18. Population evacuation or flight in Homeland Security scenarios [Creech, 1996] [Ferguson, 2003].
19. Crowd control security operations for major events, e.g., Olympic games [Swaney, 2002].
20. General crowd control operations [Bruzzone, 1999] [Miller, 2002a].
21. Movement behaviors: stay at a point, move to a point, follow an entity, move with neighbors (flocking), and stay within or beyond a distance from a point or entity [Reece, 2002].
22. Individual actions: perform mission, maintain personal safety, satisfy curiosity, and confront antagonists [Reece, 2002].
23. Crowd actions: respond to crowd actions [Reece, 2002].
24. Needed crowd behaviors: seek goal, flocking, safe wandering, following, goal change, group control [Musse, 1998].
25. Protection of civilian populations [OneSAF, 2001].
26. Civilian transport by combat entities [OneSAF, 2001].
27. Crowds in stability and support operations: "displaced civilians, refugees, mass migration, rioters, disaster victims" [OneSAF, 2001].

Training, operational. For this use category, the specific crowd modeling requirements identified were as follows:

1. Operational constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage"). At the operational level less detail and fidelity in crowd behavior is needed than at the tactical level [Sokolowski, 2003].
2. Needed crowd size: "Somalia" [Bailey, 2003].
3. JTLS has a limited ability to simulate crowds using neutral sides, but those "crowds" have no autonomous behavior generation capability; instead human operators control their actions [Sokolowski, 2003] [Ferguson, 2003]. Autonomous crowd behavior generation is needed if crowds are to be used effectively.
4. Urban warfare [Sokolowski, 2003] [Bailey, 2003].
5. Noncombatant evacuation operations (NEO) [Sokolowski, 2003].
6. Military operations other than war (MOOTW) [Sokolowski, 2003].
7. Homeland security operations [Sokolowski, 2003]; including crowd response to events such as natural disaster, terrorism, industrial accidents, disease epidemics [Ferguson, 2003].
8. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
9. Trafficability problems and road network congestion, especially at bridges and other choke points [Ferguson, 2003].
10. Displaced personnel requiring humanitarian assistance; such persons consume logistical supplies, requiring re-supply of food and water, and affect logistics of combat operations [Ferguson, 2003].
11. Movement of non-combatant people and vehicles to provide "clutter" to obscure military movements for sensor platform operations and for intelligence processes such as fusion, correlation, and targeting [Ferguson, 2003] [Swaney, 2002].
12. Crowd hysteria and confusion caused by misinformation or partial situational awareness [Ferguson, 2003].
13. Population evacuation or flight in Homeland Security scenarios [Creech, 1996] [Ferguson, 2003]
14. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].
15. Crowd control security operations for major events, e.g., Olympic games [Swaney, 2002]
16. General crowd control operations [Bruzzone, 1999].

Training, strategic. No requirements were identified for this use category.

Analysis, tactical. For this use category, the specific crowd modeling requirements identified were as follows:

1. Tactical constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage") [Sokolowski, 2003] [OneSAF, 2001]. At the tactical level more detail and fidelity in crowd behavior is needed than at the operational level [Sokolowski, 2003].
2. Needed crowd size: ~100 persons [Sokolowski, 2003].
3. Urban warfare [Sokolowski, 2003].
4. Noncombatant evacuation operations (NEO) [Sokolowski, 2003].
5. Military operations other than war (MOOTW) [Sokolowski, 2003].

6. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
7. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Kenny, 2001].
8. Needed crowd behaviors: move randomly in scenario area, approach battle, flee battle, take hostile action against combatants (e.g., throw rocks), assist combatants (e.g., provide medical aid), conduct negotiations, ask for assistance, react to threats, react to directions concerning movement, riot to acquire food [Sokolowski, 2003].
9. Displaced personnel requiring humanitarian assistance; such persons consume logistical supplies, requiring re-supply of food and water, and affect logistics of combat operations [Ferguson, 2003] [OneSAF, 2001].
10. Movement of non-combatant people and vehicles to provide "clutter" to obscure military movements for sensor platform operations [OneSAF, 2001].
11. Population evacuation or flight in Homeland Security scenarios [Creech, 1996]
12. General crowd control operations [Bruzzone, 1999].
13. Needed crowd behaviors: seek goal, flocking, safe wandering, following, goal change, group control [Musse, 1998].
14. Protection of civilian populations [OneSAF, 2001].
15. Civilian transport by combat entities [OneSAF, 2001].
16. Crowds in stability and support operations: "displaced civilians, refugees, mass migration, rioters, disaster victims" [OneSAF, 2001].

Analysis, operational. For this use category, the specific crowd modeling requirements identified were as follows:

1. Operational constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage"). At the operational level less detail and fidelity in crowd behavior is needed than at the tactical level [Sokolowski, 2003].
2. JTLS has a limited ability to simulate crowds using neutral sides, but those "crowds" have no autonomous behavior generation capability; instead human operators control their actions [Sokolowski, 2003] [Ferguson, 2003]. Autonomous crowd behavior generation is needed if crowds are to be used effectively.
3. Urban warfare [Sokolowski, 2003].
4. Noncombatant evacuation operations (NEO) [Sokolowski, 2003].
5. Military operations other than war (MOOTW) [Sokolowski, 2003].
6. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
7. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Kenny, 2001].
8. Population evacuation or flight in Homeland Security scenarios [Creech, 1996]
9. General crowd control operations [Bruzzone, 1999].

Analysis, strategic. No requirements were identified for this use category.

Experimentation, tactical. For this use category, the specific crowd modeling requirements identified were as follows:

1. Tactical constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage") [OneSAF, 2001].

2. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
3. Needed crowd size: "Somalia" [Bailey, 2003].
4. Urban warfare [Bailey, 2003].
5. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
6. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].
7. Displaced personnel requiring humanitarian assistance; such persons consume logistical supplies, requiring re-supply of food and water, and affect logistics of combat operations [Ferguson, 2003] [OneSAF, 2001].
8. Movement of non-combatant people and vehicles to provide "clutter" to obscure military movements for sensor platform operations [OneSAF, 2001].
9. Non-combatant people and vehicles to complicate situational awareness for simulation users and confuse sensors; sensors includes satellites, micro-sensors, unmanned air vehicles, and cell phone monitors; 100% fidelity not required [Cerri, 2002].
10. Interoperable with entity level (tactical) simulations [Cerri, 2002].
11. Needed crowd behaviors: comply with or violate cordons, comply with or violate curfews, react to road closings, react to food shortages [Cerri, 2002].
12. Civilian groups based on regional demographics, with various behaviors; "organized/disorganized, peaceful/hostile, active/reactive" [McLarney, 2002].
13. Vehicular traffic based on regional demographics, including vehicle type, density, and region-specific patterns [McLarney, 2002].
14. Protection of civilian populations [OneSAF, 2001].
15. Civilian transport by combat entities [OneSAF, 2001].
16. Crowds in stability and support operations: "displaced civilians, refugees, mass migration, rioters, disaster victims" [OneSAF, 2001].

Experimentation, operational. For this use category, the specific crowd modeling requirements identified were as follows:

1. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
2. Needed crowd size: "Somalia" [Bailey, 2003].
3. Urban warfare [Bailey, 2003].
4. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
5. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].
6. Non-combatant people and vehicles to complicate situational awareness for simulation users and confuse sensors; sensors includes satellites, micro-sensors, unmanned air vehicles, and cell phone monitors; 100% fidelity not required [Cerri, 2002].
7. Interoperable with aggregate level (operational) simulations [Cerri, 2002].
8. Needed crowd behaviors: comply with or violate cordons, comply with or violate curfews, react to road closings, react to food shortages [Cerri, 2002].

9. Civilian groups based on regional demographics, with various behaviors; "organized/disorganized, peaceful/hostile, active/reactive" [McLarney, 2002].
10. Vehicular traffic based on regional demographics, including vehicle type, density, and region-specific patterns [McLarney, 2002]

Experimentation, strategic. No requirements were identified for this use category.

Acquisition, tactical. For this use category, the specific crowd modeling requirements identified were as follows:

1. Tactical constraints imposed by crowds, including restrictions on movement ("don't move over") and free use of firepower ("avoid collateral damage") [OneSAF, 2001].
2. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
3. Needed crowd size: "Somalia" [Bailey, 2003].
4. Urban warfare [Bailey, 2003].
5. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
6. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].
7. Displaced personnel requiring humanitarian assistance; such persons consume logistical supplies, requiring re-supply of food and water, and affect logistics of combat operations [Ferguson, 2003] [OneSAF, 2001].
8. Movement of non-combatant people and vehicles to provide "clutter" to obscure military movements for sensor platform operations [OneSAF, 2001].
9. Protection of civilian populations [OneSAF, 2001].
10. Civilian transport by combat entities [OneSAF, 2001].
11. Crowds in stability and support operations: "displaced civilians, refugees, mass migration, rioters, disaster victims" [OneSAF, 2001].

Acquisition, operational. For this use category, the specific crowd modeling requirements identified were as follows:

1. In homeland security operations, models of crowd behavior in particular and population behavior are needed; these may be the same [Sokolowski, 2003].
2. Needed crowd size: "Somalia" [Bailey, 2003].
3. Urban warfare [Bailey, 2003].
4. Crowd behavior in response to non-lethal weapons used for crowd control [Sokolowski, 2003] [Bailey, 2003] [Kenny, 2001].
5. Needed crowd behaviors: react to gunfire, react to military police, react to barriers, drive vehicles, employ crude or improvised weapons, take hostile action against other crowd members, be repelled, threaten checkpoint, attack barrier, burn objects [Bailey, 2003].

Acquisition, strategic. No requirements were identified for this use category.

4.5 Crowd modeling requirements comments

In addition to specific requirements, some sources asserted a general need for crowd modeling [Miller, 2002b] [Reece, 2002] [Pew, 1998] [Fields, 2000] [DAF, 2003] or training in dealing with crowds in various contexts [Kenny, 2002].

Some sources observed that in simulation-supported training contexts the lack of crowd modeling capabilities might have influenced the training objectives; i.e., training objectives were established that did not require crowds because that capability was known to be not available [Sokolowski, 2003] [Ferguson, 2003]. This is an undesirable situation.

Some sources emphasized the logistical effects that crowds of displaced persons could have on friendly forces. For example:

> "[Crowds of non-combatants] will consume logistic supplies, etc., driving the training audience to look at re-supply of food and water, and assess the logistical impact on combat operations. The US will rarely, if ever, allow a displaced personnel problem to devolve into a humanitarian crisis. Operating forces will be challenged to maintain their own momentum and handle refugees." [Ferguson, 2003]

The need for an explicit psychological basis for crowd behavior modeling was not clearly established by the sources. Some sources discounted the need for psychological modeling for crowd simulation, while others saw sought greater fidelity based on psychological models as increasing simulation utility:

> "Lack of science causes some lack of value in analytical results, prevents us from access to root causes of effects, makes crowds 'black boxes'." [Bailey, 2003]

To exemplify this difference, these seemingly contradictory excerpts are from the same source:

> "Due to the limited training objectives at the operational level, I do not think that a psychological basis would be required." [Ferguson, 2003]
>
> "Currently there is little 'behavioral' aspect to the objects and entities, as they exist in the current models. Behavioral object states such as passivity, hostility, aggressiveness, confusion, could all contribute to an [entity's] behavior and the reliability of the information output by the simulation." [Ferguson, 2003]

In any case, the sources were more interested in the capabilities than the implementation method, and psychological modeling would be part of the latter.

Some of the sources made a distinction between crowds and population. The following excerpt, for example, shows considerable insight into the issue of how and when a group of previously independent persons from the population could become a 'crowd':

> "I look for [a model] that does 'normal' civilian activities and scales in response vice a crowd or a mob to start. To me there is a difference. ... The people moving through the NY streets doing Christmas shopping are not a crowd to me. The "street" is crowded but the people are not a crowd, as they have no ulterior group purpose. Crowds can be formed by external stimulation: traffic accident, bomb blast, street vendor/performer, etc. To me the difference between a crowd and just normal traffic is density and an interest in a common theme. However, [they are] still relatively mindless and benign. Mobs share [a] crowd's density but differ in a direction/purpose and leadership. Mobs have emergent leaders - crowds don't .... The leaders may be plants but members are civilian civilians. In all three cases above I think we are talking about civilian civilians transiting up a scale of complexity. I consider this different than what we experienced in Seattle or Mogadishu. There, military and law enforcement activities were up against a planning, fore thinking enemy with premeditated direction and actions, which is a little different problem set." [Cerri, 2002]

Another difference between crowds and population is scale. Crowds usually occupy a reasonable constrained area for a limited time, and their actions are reasonably focused, e.g., "storm the food warehouse". By comparison, a population may occupy a large geographical region more or less indefinitely, and their actions are often unfocused, such as "commute" or "evacuate the city". Other sources conflated crowds and population two into a single issue. For example, both crowd and population behaviors can be understood in this statement:

"[Homeland Security] training objectives driven by natural disaster, terrorism, large industrial accidents, disease or epidemic control would be greatly enhanced by crowd modeling." [Ferguson, 2003]

From a modeling point of view, the distinction between crowd and population is worth preserving, because modeling crowd-specific behaviors, such as providing human shield cover for combatants, appear to require rather different modeling techniques than modeling general population effects, such as large-scale citizen evacuation (e.g., [Creech, 1996]).

4.6 Requirements analysis findings

The sources identified a wide variety of crowd modeling requirements, expressing those requirements in a variety of ways, including crowd behaviors, military missions, and crowd effects. We elaborated the distinctions between application areas and warfare levels and associated the requirements with them to make apparent the different requirements for crowd modeling in simulations in each of the use categories. From those requirements follows the primary finding of this requirements analysis: a single crowd behavior model is unlikely to satisfy all of the requirements.

This finding has two implications. First, research and development efforts aimed at developing a crowd model should be explicitly oriented towards its intended uses (i.e., application area and warfare level) and the requirements associated with those uses; of course, this has been previously asserted for human behavior models in general [Chandrasekharan, 1999]. Second, because multiple crowd models are likely to be needed to meet all the crowd modeling requirements in military simulation, a technical capability to compare the effects, fidelity, and utility of different crowd models would therefore be useful.

A secondary finding[10] is that crowd modeling requirements seem to most important at the tactical level, of some importance at the operational level, and not important at the strategic level of warfare. Indeed, no requirements were expressed for crowd modeling at the strategic level. One possible interpretation of the latter outcome is that crowds are simply not significant at that level of warfare; another is that the sources consulted were focused on the tactical and operational levels. In any case, if there are crowd modeling requirements at the strategic level, it is likely that they are rather different from the tactical and operational requirements, and this supports the primary finding.

[10] This is really more of an observation than a finding.

5. Psychological and computational models of crowd behavior

In this section, a survey of the state of the art in psychological and computational models of crowd behavior is presented. First, an introduction to the issues of crowd behavior motivates the survey. Following that, the methodology used for the survey is explained. Then the psychological research literature on crowd behavior is covered. Next, computational models of crowd behavior are reviewed. Finally, summary findings of the survey are listed.

5.1 Introduction

Missions are changing for the United States Armed Forces, especially those of the Army and Marine Corps. They are increasingly likely to be conducted in urban or built-up areas with combatants hiding between the innocent and the use of "technicals" such as city buses, taxicabs and pickup trucks mounted with machine guns. Defeating adversaries without destroying the city while minimizing civilian casualties and maintaining popular support is the challenge [Hall, 2000]. As has been recently seen, this is an ongoing challenge in Operation Iraqi Freedom. A critical need exists for Military Operations in Urban Terrain (MOUT) training by our armed forces and the entire spectrum of military training needs to be examined [Greenwald, 2002]. Virtual simulation has a significant part to play in developing an acceptable level of expertise in MOUT. The way in which training tasks in the virtual environment, including those psychological characteristics of crowd behavior are played out needs to be addressed.

Stability missions in urban areas such as in the cities of Bosnia have provided many lessons for dealing with fighting crowds [Greer, 2000]. The crowds that Greer describes in Bosnia were not spontaneous formations of people with complaints. They were the result of a planned response to the stabilization force operation. Greer calls this type of crowd a "rent-a-crowd" as many of the people in the crowd were paid up to 100 German Marks to demonstrate against or attack the stabilization force. The crowds knew that the forces would not knowingly hurt civilians or unarmed protesters. This crowd used rocks and sticks as their weapons and later Molotov cocktails in attempts to set vehicles on fire. The crowd consisted of women and children as well as men of every age. Instigators in the crowd consisted of military-aged men who also engaged in hand-to-hand combat with the troops. The crowds of Serbs usually numbered several hundred against a single platoon of about twenty soldiers. The crowds generally fought for short intense periods followed by retreat and periods of rest and eating where they awaited further instruction from the instigators. The Serbs had maintained control of the crowd by signaling them to assemble with air raid sirens and local radio stations to provide instructions. These tactics resulted in crowds of 500-800 to assemble within thirty minutes of the first siren. The crowds sang patriotic Serb songs to raise the intensity of the demonstrations. These tactics allowed for excellent control of the Serb crowds.

Several lessons learned that worked according to Greer include keep moving utilizing speed, mobility and height; using multiple platoons to approach from different directions breaking up the crowd mass and causing confusion; tire the crowd as they chase vehicles and attempt to overcome soldiers behind well built barricades. Some lessons of what did not work include using grenades, tear gas, or negotiation.

The realities of conflicts such as this in Bosnia and now in Iraq are increasingly common. The question of training and preparing our forces for the array of possible crowd types and behaviors is challenging but not impossible with a modeling and simulation approach. Training objectives for modeling and simulation need to enrich such worlds with virtual humans—autonomous agents that support face-to-face interaction with people in these training environments in a variety of roles, such as in Varwell's four main crowd types: aggressive crowd, an escaping crowd, an acquisitive crowd and an expressive crowd [Varwell, 1978]:

1. *Aggressive.* Aggressive clearly describes the sort of situation where a crowd is intent upon destruction of some sort or another.
2. *Escapist.* A crowd may be intent upon escape. These circumstances may arise when a serious fire or explosion occurs in a dance hall or in a busy hotel, when what was originally a passive crowd becomes frightened.
3. *Acquisitive.* A crowd may become acquisitive and begin looting for various reasons
4. *Expressive.* The purpose of the crowd may be expressive - it may be primarily concerned with the expression of feelings or emotions.

An important point is that crowds can exist for any combination of these reasons. Further, a crowd can change its type due to the unfolding situation [Moore, 1990]. Virtual crowds can be varied on many pertinent dimensions. These include composition, ethnicity, size, noise, cause, location, weapons, verbal abuse, projectiles and the use of women, children and elderly as human shields. The paradox of a "crowd psychology" makes this an even more difficult task considering people's individuality, judgment, and critical thinking are subsumed by the group, while the breakdown of social structure simultaneously results in more individualistic acts of asocial behavior [Dupuy, 1990].

5.2 Survey methodology and goals

A survey of crowd research was conducted. The survey included both books and articles relating to crowds and groups. The work draws largely from the cognitive psychology, social psychology, sport psychology, sociology, police, and military literature. Research of primary interest was non-combatant crowd behavior during military operations. The secondary literature, which was much more plentiful, was focused on riots and sport fan behavior. Search terms included crowds, crowd psychology, collective behaviors (and "behaviors"), collective decision-making, mass behavior, gatherings, groups, non-combatants, consensus in crowds, military operations in urban terrain, urban warfare, mobs, riots, fan violence, flash points, crowd models, crowd control, and intelligent agents. Databases for the searches included WorldCat, InfoTrac, Ovid, Google, Proceedings First, and PsycInfo. Articles and books were evaluated on the following criteria: psychological basis, closeness to implementation as a computational model, relevance to military scenarios, level of detail, validation, quantitative data about crowd behavior.

5.3 Psychological research on crowd behavior

Relevant research from both the cognitive and the social domains of psychology guides the development of models of crowd behavior in military scenarios. Factors that contribute to aggressive crowd behavior have been studied by social psychologist such as McPhail [McPhail, 1991] and Horwowitz [Horowitz, 2001]. There is not uniform agreement on the particulars, but in general the common factors that tend to contribute include: presence of weapons, authoritarian government, lining up behind a barricade, drawing lines between "us" and "you", dramatizing issues (e.g., in a speech) and making victims, large spatially concentrated crowds, and presence of television camera and crew [Silverman, 2002].

There are relatively few studies of crowd aggression that address personality measures as independent variables [Forward, 1970] [Meier, 1941] [Ransford, 1968]. Consequently, explanations regarding the sorts of people involved tend to rely almost exclusively on a mix of speculation and generalizations from the social-experimental literature [Russell, 1995]. Confirming evidence of participants in crowd violence or would be participants is sparse not only for this reason but also for methodological differences in observation. There is ongoing debate as to the psychological nature of crowds as well as the very existence of such an entity or rather should it be called a gathering of small clusters.

Recent conclusions by Kenny et al. [Kenny, 2001] have pointed to the difficulties in examining crowds due to their diverse nature of the participants not only within the crowd but also across time, cultures, and individual motives. There is clearly a lack of unanimity of motivation or crippled individual cognition as was once advocated by some of the earliest investigators of crowd behaviors [Le Bon, 1895]; [Park, 1904] [Park, 1930]; [Blumer, 1939]. Kenny et al. [Kenny, 2001] indicate the need for more research to address the unknowns of crowd behavior as well as to test new theories against existing ones recognizing discrepancies. Ideally, such research would allow for models to be built with probabilities of specific crowd behavior. Further basic research is needed to address the psychological variables that have been related to crowd behavior in order to establish such probabilities of occurrence in a specific scenario within various cultures of eminent interest.

5.3.1 Phases of gathering

Kenny et al. [Kenny, 2001] identify three specific phases of a gathering: assembling, gathering and dispersal. The first stage is known as assembly. This stage consists of the process and motivation behind the initial collection of people. For example, the crowd may assemble for a planned event or people may collect without warning. The assembly stage contains variables that determine the motivation behind this collective activity [Kenny, 2001].

Once the crowd has assembled it enters the gathering stage; the second stage in a crowds evolution. During this stage a crowd begins to engage in collective behaviors. These behaviors can range from peaceful actions such as singing or cheering to violent behaviors and the use of weapons. One example of this type of behavior was seen in the Los Angeles race riots following the Rodney King verdict in 1992. A more violent example is the conflict between American troops and thousands of heavily armed Somalis in Mogadishu in 1993. Most recently, the protesters of the Seattle World Trade Organization meeting in 1999 involving a large mix of activists and anarchists, from around the world, who were intent upon disrupting the launch of the new organization.

Eventually the crowd will discontinue its collective behaviors and disperse. Crowd dispersal is the final stage of a crowd's evolution and this process may be either forced or routine. The type of dispersal that occurs often depends on several factors present during this stage [Kenny, 2001].

Kenny's model provides peacekeeping forces with a starting point for understanding crowd behavior, however, this theory lacks a complete examination of crowd dynamics and the variables that cause violent crowd behavior. Several researchers have adopted the flash point philosophy to help further uncover this dimension of crowd dynamics [Kenny, 2001] [Waddington, 1987]. According to these researchers, a "flash point" is the point at which seemingly docile crowds suddenly become violent in response to a trigger or stimulus. The violence may be a response to any number of factors.

Assembling	Gathering	Dispersal
• Territoriality [Weller, 1985] • Presence of agitator [Meyer, 1978] [Feinberg, 1988] • Presence of police [Aveni, 1977] • Curiosity [Berk, 1974] • Political events [Sullivan, 1977] • Time stress [Berk, 1974] • Media violence [Weller, 1985] • Presence of media [Silverman, 2002] • Making a statement [Fogelson, 1971] • Proximity to speaker [Meyer, 1978] • Racial event [Weller, 1985] • Religious [Duggan, 1990] • Frustration [Berk, 1974] [Dollard, 1947] • Potential for reward [Berk, 1974] • Communication [Sullivan, 1977] [McPhail, 1973] • Association with known others [Aveni, 1977] [McPhail, 1985] • Boredom [Berk, 1974] • Time of day [Stark, 1972] [Stark, 1974] • Homogenity [Feinberg, 1988] [Derlega, 2002] • Convenience [Aveni, 1977] • Comfort [Aveni, 1977] • Self efficacy [Bandura, 1977]	• Presence of other like-minded [Berk, 1974] [Blumer, 1936] [Klapp, 1972] • Proximity to like minded [Berk, 1974] • Weapon availability [Berkowitz, 1964] • Opposition [Canetti, 1981] • Knowledge visibility [Berk, 1974] • Fatigue [Berk, 1974] • Conformity [Weller, 1985] • Ignorance of others' reactions/motives [Berk, 1974] • Age [Russell, 1998] • Physically Aggressive [Russell, 1998] • Gender [Russell, 1995] • Single [Russell, 1995] • Underemployment [Russell, 1995] • Commitment to cause [Derlega, 2002]	• Fatigue [Berk, 1974] • Control of media [Veno, 1992] • Disappointment [Duggan, 1990] • Perception of own strength/self-efficacy [Bandura, 1977]

Table 1. Summary of psychological variables and research that affect crowd behavior.

This perspective is more of a process than an entity and provides a useful taxonomy for summarizing the literature. A sampling of relevant psychological variables that have been examined in the crowd context can be related to each of these phases.

5.3.2 Characteristics of rioters

Russell & Arms [Russell, 1998] showed that would-be rioters tend to be younger and physically aggressive. They also tend to be male and single [Russell, 1995]. The evidence that they are variously described as underemployed, disaffected or marginally employed and economically disadvantaged males has also been consistently shown in a wealth of studies by European sociologists investigating football hooliganism [Adang, 1992] [Bakker, 1990] [Murphy, 1990] [Pilz, 1989] [Roversi, 1991] [Van der Brug, 1992] [Van Limbergen, 1989] [Zani, 1991]. Haddock and Polsby [Haddock, 1994] note similar characteristics of the Los Angeles rioters. Not only did they conclude that they were largely poor, underemployed and victims of racism but also unique in their jubilant moods rather than fury as they ran with their new cameras and VCR's. "It is hard to accept that these rioters were protesting the jury system, the state of race relations in Southern California or anything else--they were, in fact, having a party" (p. 1).

The Russell [Russell, 1995] study found that those admitting to strong inclinations to assault, those attracted to violence also exhibited psychopathic, or antisocial personality, tendencies. In addition to a proclivity for aggression, psychopathic inclinations has been variously seen to include: a lack of empathy, guilt, remorse, and fear of punishment, an extreme degree of selfishness, impulsiveness, and irresponsibility, a callous disregard for the feelings and welfare of others, weak inhibitory controls" [Williamson, 1987] [Hare, 1994]. This in addition to the strong tendency of antisocial youths to perceive hostile intent in others [Sarason, 1978] and the result is that public disorders become an even greater likelihood.

5.3.3 Cognitive components

Russell [Russell, 1995] also found a cognitive component in his study. Subjects' attraction to the fights was positively related to their estimates of the percentage of other fans that were in attendance for the same reason, to see a fight. This effect has been described as the false consensus effect [Ross, 1977]. In other words, if the spectators feel that other like-minded spectators are also there to see a fight then there is a general acceptance for aggression. These spectators are emboldened by the thought that others will not only approve but also applaud and cheer them on in joining a fight.

5.3.4 Locus of control

In a study of the Watts riots by Ransford [Ransford, 1968] locus of control was linked to violent behavior of crowds. In an interview of 312 male heads of households conducted while buildings were still smoldering, Ransford asked "Would you be willing to use violence to get Negro rights?" Those with a belief in an external locus of control, or alternatively, men who felt powerless in their circumstances were more willing to resort to violence as a solution [Russell, 1995]. Age was not a factor. However, in another study by Forward and Williams [Forward, 1970] of a much younger sample, aged 12-18 years, and using a different measure of locus of control the opposite was found. These younger black males with favorable attitudes toward violence instead had an internal locus of control orientation.

5.3.5 Personality factors

Meier et al. [Meier, 1941] examined the personality factor of extroversion/introversion. They showed subjects a scenario describing an escalating riot. Those who indicated that they would likely take part in the mob action were predominantly males who exhibited tendencies toward extroversion and lower intelligence.

5.3.6 Territoriality

Territoriality is one of the more basic areas of ethnological research, or the study of instinctive behavior. Humans are very sensitive to relatively minor aspects of the home territory and "tenaciously defend minor boundaries, such as those created by housing clusters, street layouts, garages and gardens, with great tenacity" [Whythe, 1961]. The need for territory for the raising of infants links aggression with courtship [Weller, 1985]. Weller concludes that the pressure to assert dominance amongst males has a sexual basis and helps to explain the prevalence of violent behavior among young men.

5.3.7 Influence of media on violent behavior

Weller [Weller, 1985] also attributes aggressive behavior to the media. The frequent exposure of experimental groups to violent incidents on film and television has led to long lasting effects [Bandura, 1965] [Bandura, 1973] [Roth, 1979]. Aggressiveness has been positively correlated in 19 year olds having viewed violent scenes on television ten years earlier [Eron, 1972]. The actual enactment of violence seems to induce further violence in children and adults [Buss, 1966] [Loew, 1967] [Nelsen, 1969] that Weller [Weller, 1985] attributes to the behavior of crowds, mobs and riots.

5.3.8 Anonymity

Empirical evidence on an individual, who believes his identity is unknown, such as in a large crowd, indicates that he is more likely to behave aggressively [Rehm, 1987] [Watson, 1973]. A more recent study by Silke [Silke, 2003] found that anonymity also increases the range of a crowd's violent behavior. This effect has also been demonstrated in cross-cultural surveys. Evidence here indicates that warriors who use body or face paint are more likely to kill, mutilate and torture captured prisoners than warriors who do not use such masking [Watson, 1973]. Similarly, a study of violence in Northern Ireland between 1994 and 1996 demonstrates that the use of disguises by attackers was significantly more associated with aggression at the scene of the crime and with more punitive treatment of the victims. Disguised attackers also showed a wider range of aggressive behavior [Silke, 2003]. Psychologist have found that in large cities where potentially lethal emergencies, accidents, thefts, or personal attacks occur more frequently, people exhibit bystander apathy whereby they watch but seldom help in what has become known as the bystander effect [Latane, 1968].

5.3.9 Terror management theory

Terror Management Theory (TMT) is a psychological theory of how people cope with their awareness of the inevitability of death, and how a core fear of human mortality and vulnerability leads to a need for self-esteem, faith in a cultural worldview, and hostility toward those who hold different cultural worldviews [Pyszczynski, 2003]. The findings of these and other basic psychological research studies can readily be applied to a model used to determine simulated crowd behavior of foreign cultures with known ethnic customs and norms.

Incorporating a substantial body of research from anthropology and from organizational, developmental and cognitive psychology, a "Cultural Lens" model has been developed that can capture cultural differences in reasoning, judgment, and authority structure [Klein, 2002]. This model allows for someone to see the world as if through another's eyes and to understand and evaluate options as others might. This "decentering" allows the outsider to anticipate actions, judge accurately, and intervene effectively. A "decentering" training program has been developed, implemented and evaluated for use in understanding knowledge structures in terrorist groups. It can be utilized in a simulated model of crowd behavior in foreign settings to develop profiles of goals, patterns, and weaknesses of new potential terrorist groups [Kein, 2002].

5.3.10 Models of crowd behavior

A model of crowd behavior created by Jager et al. [Jager, 2001] was initially developed to explore hypotheses about what might trigger riot behavior in crowded conditions. The model represents crowd behavior as internal states, with perceptual based knowledge of its environment and a repertoire of available behaviors. The model involves multiple agents, each of which belongs to one of two parties and whose interaction with agents of their own and the other party depended on the level of an agents' aggression and the number of agents surrounding that agent at a particular time [Jager, 2001]. The model demonstrated emergent behavior similar to the rioting behavior seen in actual crowd situations.

Jager makes two main assumptions about individuals in crowd conditions. The first is that the desire to fight can change within an individual, depending on the circumstances in which those individuals find themselves and what their previous experience has been. The second assumption of the model is that different people may be more or less provoked in any given situation. The model utilizes a relatively simple framework that allows for possible variation in simulation. The first model behavior is clustering which varies in size and may be composed of agents from different parties. The second model behavior is global agent disposition representing varying levels of aggression. Each of these model behaviors will influence the others. For instance, decreasing the disposition will result in agents moving towards members of their own party if their own party outnumbers the other party yet when disposition is high party members move toward the party with the largest number of members. Similarly, decreasing vision and number of agents slows down clustering because of the increase in time required to cluster. Keeping the variables in mind makes it possible to more accurately develop a simulation modeling possible military scenarios in foreign urban settings of varying ethnic composition.

5.3.11 Crowd management and control models in the military

Crowd management and control models based on both military Command and Control and Management Information System concepts have been utilized and validated by police chiefs and urban administrators to develop procedures for massive demonstrations [Alghamdi, 1992]. These models are based on military and civilian law enforcement experiences with pre-planned managed events, "spontaneous" demonstrations, terrorism, riots, natural disasters, and even peaceful special events and demonstrations requiring extreme management concentration. The model is separated into two phases, the crowd management phase and the crowd control phase. Both phases support the Command Center control teams. The crowd management phase pre-supposes prior notification of an event. Crowd management incorporates management information concepts that apply the management of technological and human resources in a dynamic environment. It utilizes important modeling and simulation considerations of support activities such as planning, data base design, scenario generation, event modeling and training.

The crowd control phase within the model is precipitated by an unanticipated incident similar to those needed for training of MOUT exercises. The emphasis is on the essential Command and Control coordination concepts that permit complex operations to function in a coordinated way. Here, Command and Control has two central functions: situation modeling and resource allocation. Situation modeling requires the fusion of data from all sources. Resource allocation is a decision making process for the marshalling and direction of equipment and manpower under a unified command. Systems that support this process include event evaluation systems, decision support systems and crowd control planning and monitoring systems.

5.3.12 Group inter-relationship

A model of human crowd behavior focusing on group inter-relationship and collision detection variables proposed by Musse & Thalmann [Musse, 1997] treats the individuals as autonomous virtual humans that react in presence of other individuals and change their own parameters accordingly. The model's focus is on individual and group parameters and distributed group behaviors to determine the global effect generated by local rules. The group parameters include defining the goals as specific positions that each group must reach, number of autonomous virtual humans in the group, and the level of dominance from each group. The individual parameters are a list of goals and individual interests for these goals, an emotional status, the level of relationship with the other groups, and the level of dominance following the group trend. This rather simplified model may assist in the development of a simulation of crowd behavior by focusing on the group inter-relationships.

Johnson and Feinberg [Johnson, 1977] describe a model of the internal dynamics of crowd processes based on the idea that crowds strive to reach a consensus for behavior through a process of interaction or milling. They report that individual crowd members seek support from a sample of crowd members. The successful ones attempt to influence the crowd toward a particular course of action. Consensus is achieved with a sufficiently reduced variability of opinions in the crowd. Independent variables examined include the initial distribution of opinions, crowd suggestibility and the average position of individuals seeking to influence the crowd. Findings indicate that most of the simulated crowds reach consensus within a given time limit; rapidity and extremity of consensus are considerably affected by interaction among the manipulated variables.

This finding is supported by recent research [Derlega, 2002] in a test of inter-group relations and social identity theory. Here, subjects were asked how they would respond to a conflict, either with another individual, between their group and another group or between their country and another country. Participants responded more negatively to inter-group and international conflicts than to interpersonal conflicts. Self-construal, or the feeling that one is separate and bounded from others [Markus, 1991], moderated this effect. Collectivist cultures emphasize the development of an interdependent construal of self, and individualistic cultures emphasize the development of an independent construal of self [Singelis, 2000]. Controlling for country of origin, subjects who were high in interdependence endorsed threat more and acceptance of the other's demands less in an international conflict versus an interpersonal conflict. Those low in interdependence differed less in their endorsement of conflict resolution strategies in an international versus an interpersonal conflict. These findings would support the development of a model of crowd behavior in different cultures once the level of agreement is established.

The presence of outside agitators is another variable examined in a crowd behavior model offered by Feinberg and Johnson [Feinberg, 1988] to determine the success of an extremist leading a group into "radical" action by a gathering of moderates not otherwise disposed to militancy. Findings indicate the variables most related to agitator success are crowd suggestibility, the action-choice advocated by the agitator, and the probability of movement within a physical space. Thus, the agitator is likely to be successful only in the specific and infrequent circumstances of a small gathering in a highly ambiguous situation in which the crowd members are not suspicious of the outsider.

A third body of research suggests a strong link between environmental variables and crowd violence. For example, Stott and Reicher [Stott, 1998] believe that in some cases the presence of a perceived environmental threat, such as a police force, may cause a crowd to display hostile behavior toward that threat. Crowds may also become more aggressive in the presence of an aggressive or violent activity such as a violent sporting event [Miller, 1993]. Finally Feinberg and Johnson [Feinberg, 1988] found that an ambiguous environment is one factor that causes a crowd to become more readily accepting of violent behavior.

Several researchers believe that violent crowd behavior is not the result of predisposition or emergent group norms but is instead due to the complex interaction between individual and group goals [McPhail, 1991]. This interaction determines the crowd's type or mission; a fourth factor that may lead to violent crowd behavior. These researchers explain that each crowd member is cognitively capable of setting the terms of his or her cooperation with the group's goals. Therefore, crowd behavior is determined by the extent to which a consensus is reached between the rational calculation of the individual members and those of the group [McPhail, 1991]. Violence occurs in crowds when individual members, called agitators, successfully influence other members and direct the goals of the crowd toward violent behavior [Feinberg, 1988]. The extent to which these agitators influence individual crowd members is dependent on several variables. For example, according to Feinberg and Johnson, members of small crowds are more likely to be influenced as well as members that are not suspicious of the agitators. An earlier study by these two researchers found that the diversity of opinions and suggestibility of the individual members also affected the likelihood that these members would become coaxed into violent behavior by crowd agitators [Johnson, 1977].

Crowd research has uncovered many potential factors that can cause crowds to reach a flash point. However, the research lacks an overall structure and coordination of these variables within a psychological framework. A well-organized and comprehensive model of the factors that cause crowd violence is needed because it may enable peacekeepers to answer some important questions. First, which of these flash points are the most common among crowds? Second, which if any of these variables are consistent across all crowds and in all situations? And third, at which stage of a crowd's evolution does each of these potential flash points influence crowd behavior? Providing peacekeepers with answers to these questions will greatly contribute to the creation and implementation of training programs designed to help eliminate this violence.

5.4 Computational models of crowd behavior

Crowd simulation is becoming increasingly common in special effects for movies and games. Examples of such efforts include the crowd of digital passengers waving farewell on the Titanic or the army androids of soldiers in the recent Star Wars episodes. Further, sports games often include large numbers in spectator crowds with very limited and simple behaviors. These special effects lack the element of real time necessary for computer-generated crowds in virtual reality educational or training systems [Ulicny, 2002]. Real time applications pose the challenge of handling interactions among crowd agents as well as the limited computational resources available.

The science of crowd simulators has been conceived from a number of more basic fields of study. Reynolds [Reynolds, 1987] first studied distributed behavior modeling for simulating the aggregate motion of a flock of birds. He revolutionized the animation of flocks of animals, in particular birds, or "boids", by utilizing theories from particle systems relating each individual bird to a particle. Individual and collective actions were studied in what McPhail et al. [McPhail, 1992] prefer to call temporary gatherings. A technique utilizing a combination of particle systems and transition networks to model human crowds in the visualization of human spaces employed by Bouvier and Guilloteau [Bouvier, 1996] was the basis of later work in agent dynamics. Brogan and Hodgins [Brogan, 1997] addressed the issue of significant dynamics in simulating group behaviors. Their work simulated groups of creatures traveling in close proximity, whose motions are guided by dynamical laws. The focus to this type of animation is on collision avoidance.

Virtual humans have been represented through dynamically generated impostors in the work of Aubel and Thalmann [Aubel, 2000]. Mobile cellular agents moving in an automatic fashion were used by Still [Still, 2000] in the simulation and analysis of crowd evacuations. Tecchia et al. [Tecchia, 2002] employed image-based methods for real-time rendering of animated crowds in virtual cities. O'Sullivan et al. [O'Sullivan, 2002] presented the Adaptive Level of Detail for Human Animation (ALOHA) model of crowd and group simulation. The ALOHA model incorporates levels of detail for not only geometry and motion, but also includes a complexity gradient for natural behavior both conversational and social. Few models [Musse, 2001] [Ulicny, 2001] have attempted to examine more general crowd behaviors, integrating several sub-components such as collision-avoidance, path-planning, higher-level behaviors, interactions or giving up. In Musse and Thalmann's [Musse, 2001] ViCrowd system a virtual crowd can be created where the individuals have variable levels of autonomy including scripted, rule-based, and guided interactively by the user [Musse, 1999].

Ulicny and Thalmann [Ulicny, 2001] advocate a real-time crowd simulation with an emphasis on individuals in contrast to groups in a multi-agent system. Levels of variety range from zero variety where for a given tasks there is only a single solution; to level one where it is possible to make a choice from a finite number of solutions; and level two, where it is able to use solutions chosen from an infinite number of possible solutions. Seo et al. [Seo, 2002] exemplify such a model whereby a level one system presents a crowd that is composed of multiple humans selected from a pre-defined set composed of sets of exchangeable parts such as heads, bodies, and textures. A level two system described in the same study displays a potentially infinite number of unique humans generated by a parameterized anthropometric model generating humans with different morphologies. Ulicny and Thalmann [Ulicny, 2002] point out that such higher levels of variety can be unnecessary when perfect visualizations are distracting and simpler uniform visualizations could help emphasize problems.

The model of the world varied by Ulicny and Thalmann [Ulicny, 2002] distinguishes between dynamic and static objects and environments. They define dynamic objects as those that may change place during the scenario such as fire or gas clouds. Boulic et al. [Boulic, 1997] model agents with more complex visualizations. Theirs are able to perform certain low-level actions such as pre-recorded body animation sequences of gestures and changes of posture or walking to a specified location with different gaits. Varying facial animation sequences were illustrated by Goto et al. [Goto, 2001] looking at specified places or playing 3D localized sounds. These lower level actions can be combined for higher-level behaviors in the Ulicny and Thalmann model [Ulicny, 2002].

Ulicny and Thalmann's [Ulicny, 2002] model of the world recognizes the importance of internal psychological or physiological states of agents. These include memory, fear, mobility, or level or injuries in simpler states. Higher-level complex behaviors include wandering, fleeing, or following a path. Agents follow a set of rules for determining the appropriate behavior as a result of the static or dynamic environment. Further, interactions between the agents and the dynamic objects simulate the reciprocal role that each plays, i.e., the effects of the agent on the fire or the effects of the fire on the agent.

Behavior models of Ulicny and Thalmann [Ulicny, 2002] focus on the perception of the agents in their surrounding environment. This includes reaction to changes, other agents and to the real humans interacting in the virtual world. Behaviors, which can be mixed as needed, range in level from simple scripted behaviors to high-level autonomous behaviors such as wandering, fleeing, neutralizing the threat, or requesting and providing help.

Ulicny and Thalmann's model is a good example of efficiently managing variety. The levels of variety for multiple agents are perhaps one of the most advanced in the concept of crowd simulation. Their current work focuses on enhancing the levels of variety and incorporating motion models able to synthesize variations of a given motion [Lim, 2002]. Further research is called for to enhance the behavior models by including new behaviors based on sociological observations from gatherings in real world settings.

5.5 Realism of agent cognition and behavior

Increasing the realism of agent cognition and behavior is a common concern of agent developers [Silverman, 2002]. Such realism contributes to transfer of training for simulators of war-gaming and operations rehearsal. Including realism in the agents contributes to improved ability to explore alternative strategies and tactics when playing against them and higher levels of skill attainment for the human trainees [Pew, 1998] [Sloman, 1999]. Silverman identifies several variables necessary for inclusion in simulators to allow for more realistic agents. Agent behaviors need to change as a function of cultural values, emotions, level of fatigue and stress, time pressures, physiological pressures, the group effectively overcoming an opposing group. All, of which may lead to limits of rationality. He notes, that in most available combat simulators the agents conduct operations endlessly without tiring or making mistakes of judgment. The agents, unrealistically, are uniform and predictable in following systematic doctrines in the defeat of their opponents.

The believability issue has been noted in the graphics and animated agent literature noting especially the lack of deeper reasoning ability of agents [Laird, 2001] [Bates, 1994] [Elliot, 1992]. Silverman emphasizes the importance and need for a focus on planning, judging and choosing types of behavior that is necessary of embodied agents. They note, perhaps most importantly, that "the human behavior literature is fragmented and it is difficult for agent developers to find and integrate published models of deeper behavior." The approach taken by Silverman investigates the duality of mind-body interaction and the impact of environment and physiology on stress and in turn, of stress on rationality. Their objective is to accurately model a crowd and predict when one may become violent while another remains peaceful.

The ability of humans to detect even slightly unnatural human behavior is a particular challenge in the simulation of crowds of humans. Realistic gestures and interactions between the individuals in the crowd are important cues for realism [O'Sullivan, 2002]. Their model emphasizes the importance of not only verbal communication but also non-verbal expression as a means of communication. They point out that many of the existing methods look great at a distance but upon closer observation it is obvious that the agents are behaving in a cyclical manner and not interacting naturally with each other. One reason, according to Sullivan et al.

[O'Sullivan, 2002], is that most of the human crowd simulations tend to follow the flocking approach presented by Reynolds [Reynolds, 1987], whereby the collision avoidance focus yields a crowd that is too sparse. A natural crowd consists of people conversing with each other, touching each other either intentionally or unintentionally. People who know each other in the crowd may be walking alongside or holding hands. Further, there are innate differences in how people react to being touched by a stranger in a crowd. Following behavioral rules of psychology makes it possible to achieve a "more chaotic, less military look to the crowds."

The O'Sullivan et al. model proposes an Embodied Conversational Agent with the same properties as humans in face-to-face conversation especially the ability to produce and to respond to both verbal and non-verbal expression. A nonverbal behavior generation toolkit called Behavior Expression Animation Toolkit (BEAT) has been developed to address this multimodal generation and interpretation of what is being said in the conversational content and how turns are managed in conversational management [Cassell, 2001] allowing for more realistic simulations of crowds.

Future work on the O'Sullivan et al. model calls for the integration of an intelligent agent based role passing technique into the ALOHA framework. Role passing involves the layering of roles on top of basic agents. This makes it possible for the agents to engage in collective motivations that recognizes psychological drives and attributes such as personality traits. Level of Detail Artificial Intelligence (LODAI) allows for incorporating these higher order behaviors in the more visible agents while omitting them for the less important agents [MacNamee, 2002].

Early work on embodied conversational agents [Cassell, 2000] and animated pedagogical agents [Johnson, 2000] has laid the groundwork for face-to-face dialogues with users. An example of such a possibility is known as Steve [Rickel, 1999a] [Rickel, 1999b], and is particularly relevant. Steve is a collaborative agent used in 3D virtual worlds who can act as a member of a crowd, a teammate or an instructor.

Steve has already been applied to Army peacekeeping scenarios. Steve's behavior is not scripted. Rather Steve consists of a set of general, domain-independent capabilities operating over a declarative representation of domain tasks [Rickel, 2002]. According to Rickel, virtual worlds like the peacekeeping example introduce new requirements [Rickel, 2002]. To create a more engaging and emotional experience for users, agents must have realistic bodies, emotions, and distinct personalities. To support more flexible interaction with users, agents must use sophisticated natural language capabilities. Finally to provide more realistic perceptual capabilities and limitations for dynamic virtual worlds, agents such as Steve need a human like model of perception. These new requirements have recently been tested in Mission Rehearsal Exercise [Swartout, 2001] implementing them in a peacekeeping scenario. The scenario uses three Steve agents (a sergeant, a medic, and a mother) who interact with the user, playing the role of lieutenant. The scenario also uses modified versions of Boston Dynamics' PeopleShop for additional scripted virtual humans in the crowd of locals and four squads of soldiers. The lieutenant's decisions influence the way the situation unfolds, culminating in a glowing news story praising the user's actions or a scathing news story exposing decision flaws and describing their sad consequences. The military is well aware of the challenges associated with training soldiers to handle difficult and stressful dilemmas in foreign cultures. This type of immersed training in realistic worlds allows soldiers valuable personalized experiences.

5.6 Survey findings

There are many variables that may influence crowd behavior. Few existing models of crowd behavior have strong underpinnings in psychology. An area of psychological research that seems particularly relevant to crowd behavior and lacking in much of the existing research is cognitive psychology. Studying social cognition factors such as schemata or strategies for decision-making, judgments, and reasoning could enhance understanding human behavior in abnormal situations such as military operations.

The question of how direct is the relationship between cognition and behavior is not an easy one to answer. There has been little research that includes behavioral dependent measures, so opportunities to examine the relationship are relatively few. One challenge to understanding the cognition-behavior relationship is that we may expect too many and too varied behaviors to be related to any given cognition. Improving measurement of cognition and behaviors is essential for determining probabilities of behavioral consequences. At issue is the level of situational specificity with which each is measured. Attitudes and behaviors may be inconsistent given a particular cultural climate such as degree of interdependence or religious conviction. This suggest that the consistency will be highest when one examines behaviors that are prototypically related to particular cognitions, but that cognition-behavior consistency will be lower when one examines behaviors that are less centrally related to the cognitions in question.

Overall, attitudes that matter to a person such as those that are based on personal experience, held with confidence or that have implications for one's future show a stronger relationship to behavior than those that matter little [Kelman, 1974]. The implication for developing models and simulations of crowd behavior is that we must consider the past experiences and the implications for one's future outcomes rather than focusing on cognitions that develop from mild curiosity or fleeting interest.

In addition to the psychological factors, situational factors may also influence the cognition-behavior relationship by making certain cognitions more salient as guides for behavior. For instance, social norms can be strong situational determinants of behavior that overwhelm seemingly relevant attitudes [Bentler, 1981]. Models of crowd behavior need to consider the presence of an audience or when one's attention is directed outward toward the situation which is when behavior is most likely to be strongly affected by self-presentational concerns [Snyder, 1978]. Therefore, to predict and model what cognitions will cohere with behavior one must understand what factors such as self-presentational concerns, prior beliefs, attributions, expectations or other influences in a situation are salient.

Future research on crowd behavior during military operations should address these more challenging areas of cognitive psychology. The people who exist within an urban area during a military operation are the only thinking component of an operational area and have the capacity to significantly modify operations [Medby, 2002]. Furthermore, the cultural differences must also be acknowledged in future research. We are seeing an increasing number of unarmed combatants being used as human shields to protect gunmen as in Mogadishu. Such conviction is very different from the cognitive processes to which American soldiers are accustomed and must also be included in future modeling and simulation endeavors.

6. Crowd federate design study

In this section a design study of a crowd simulation federate is reported. The design study was based on a set of implementation experiments; those experiments and their results are described.

6.1 Introduction

In order to learn about salient challenges and possible solutions in the implementation of a simulation of crowd behavior, we conducted a design study of such a simulation. The design study began with certain premises:

1. The crowd simulation would be implemented as a federate in a distributed simulation, and so would need to operate with an interoperability protocol such as the High Level Architecture (HLA), and other federates in the federation would be responsible for the non-crowd entities.
2. The crowd entities would be individual human characters, rather than aggregations.
3. The behavior of the crowd entities would be controlled by behavior models, rather than by a human operator.
4. The federate could be used in a virtual simulation environment, so both the behavior and the visual appearance of the crowd entities were of interest.

6.2 Design process and goals

The design process started with an investigative software development process to initially create an exploratory prototype aimed at elaborating requirements of the Crowd Behavior application programming interface (API). The goals of developing this prototype were twofold. Firstly, we mitigate risk by investigating areas of the design that contain either much complexity or involve reuse of software which may be difficult to integrate. Specifically, this involves the reuse of game AI solutions from the entertainment industry and integrating them with traditional military distributed simulation solutions. Those risk areas involve software integration and terrain correlation. Secondly, growing familiarity with the capabilities of the commercial-off-the-shelf/government-off-the-shelf (COTS/GOTS) software and the theoretical necessities of crowd behaviors and their effect on military outcomes, allow iterative refinement of the requirements of the Crowd Behavior API.

The exploratory prototype and refined requirements may now be used to implement a functional prototype designed to support the Crowd Behavior API. This prototype can be expanded as additional capabilities are needed.

This process is in effect the beginnings of a spiral development effort tailored to the goals and objectives of this project. Subsequent cycles in the spiral would be carried out in follow-on crowd modeling efforts related to this project.

Upon conclusion of the design study the following design and implementation goals were achieved:

1. A prototype was implemented that demonstrated the integration of game AI software within a military-oriented distributed simulation architecture, such as HLA. This prototype resulted in a federation that combined crowd modeling capabilities from entertainment industry software with semi-automated forces modeling capability of JSAF.
2. An initial draft of the Crowd Behavior API was achieved to a level of detail specification that can be implemented as part of a follow-on phase to this project.

3. Crowd models with differing fidelity were created. It will be important during a follow-on project to determine the effects of the different fidelity crowds on the outcome of a military mission.
4. The team also developed and correlated terrain between the game technology and the military simulation. This process was evaluated and documented.

6.3 Crowd federate architecture

This section describes design considerations and ideas for the crowd federate architecture.

6.3.1 Architecture background

Much research has been conducted on human behavior models that focus on individual autonomous human agents. Fewer models have addressed group or crowd behavior. Crowd behavior models in the literature range from purely physical representations to purely cognitive representations and combinations of both have been successful to varying degrees in the domain to which they were intended. Motivations range from improving graphical rendering performance to providing realistic behavior representations with emotions and other drivers. Crowd models include particle systems, flocking systems, or behavioral systems -- the difference being an increasing level of interaction among participants in the crowd and with the environment in general. Along with increased interaction comes increased attention to modeling the social and emotional interactions among crowd members.

A recurring theme throughout the literature is the necessity to model behavior either at the individual level and allow crowd behavior to emerge as a result of many goal-oriented individuals within the same location or the behavior of the crowd may be completely controlled by a crowd entity. Again, there is a range of efforts between these two extremes. Recent findings [Kenny, 2001] indicate that there is empirical evidence that crowds are not wholly individuals nor wholly a single entity but rather a congregation of individuals and small groups from which crowd behavior emerges out of a process of assembling, temporarily interacting, and then dispersing. This suggests there is a hierarchy of behavior needed at the individual and group level and an awareness and affect of the evolution of the crowd over time. Such complexity could only arise from behavioral models that include aspects of cognition. Nevertheless, a variety of models do exist. Where realism and human decision-making based on simulation stimuli are important, models that focus on physical visual representation of crowds are important. Where motivations and consequences take precedence over visual realism, robust cognitive models are necessary. A framework that allows the integration of diverse models at the cognitive level with differing physical models would serve to provide useful crowd models to fit a variety of needs. In recognition of this variety, the Crowd Behavior API must be flexible enough to allow such mappings of differing philosophy.

We are using COTS tools such as AI.implant, Maya, and simulation engines from the gaming and entertainment industry that provide much of the physical and visual realistic representation. AI.implant is an autonomous character tool that calculates and updates the position and orientation of each entity, chooses the correct set of animation (locomotion) cycles, and enables the correct simulation logic. Maya is a graphical design and animation tool that provides the workspace for AI.implant and produces the animation clips that a game engine would use to visualize the simulation environment.

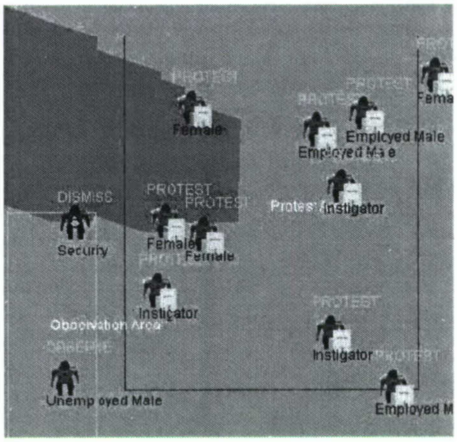

Figure 4. PMF/OPS, an existing model of crowd behavior [*Silverman, 2002*] [*Cornwell, 2002*].

Military alternatives at the physical layer of crowd representation include DISAF [Reece, 2002]. Recently, DISAF began including a flocking-based representation of crowd behavior allowing the incorporation of standing around behavior and flocking to waypoints. In addition, crowd individuals have traits such as curiosity, fear, motivation, and hostility. The mental states achieved in individuals stimulate crowd behavior resulting in stay or flee.

More robust models of crowd cognitive behavior are being developed [Silverman, 2002] [Cornwell, 2002] [Musse, 1998] [Musse, 2001] [Allbeck, 2002]. Figure 4 shows Silverman's model, called PMF/OPS. These models include crowd behaviors such as dispersing, gathering, swirling, clustering, flocking, safe wandering, following, goal changing, attraction to a location, repulsion from a location, group splitting, and space adaptability. Crowd evolution is also tracked so that one can determine whether the crowd is advancing, gathering, retreating, or dispersing. These models include environmental knowledge, group beliefs, intentions or goals, and also desires. Silverman builds a cognitive model based on Markov chains and a BDI (Belief, Desires, Intensions) model [Silverman, 2002].

Musse [Musse, 2001] in particular discuss three ways of controlling crowd behavior: 1) scripts, 2) rules with events and reactions, and 3) real-time external control. An entity hierarchy is provided where the smallest unit is the virtual human agent. Next up in the hierarchy are groups that are composed of agents and then crowds that are composed of groups. "Crowd behavior corresponds to a set of actions applied according to entities' intentions, beliefs, knowledge and perception" [Musse, 2001]. Different levels of realism are explored to support simple to complex crowd behaviors. Simple crowd behaviors would approximate crowd behavior based on flocking systems. Additionally, crowds may have a predominant emotion (sad, calm, regular, happy, or explosive which is extremely happy). These emotions may affect the posture and walk characteristics of individuals.

Our desire is to benefit from the variety of models by creating an architecture with an API specifically to support crowd behaviors in distributed simulations. This framework would allow the integration of robust cognitive models with models existing at the physical layer.

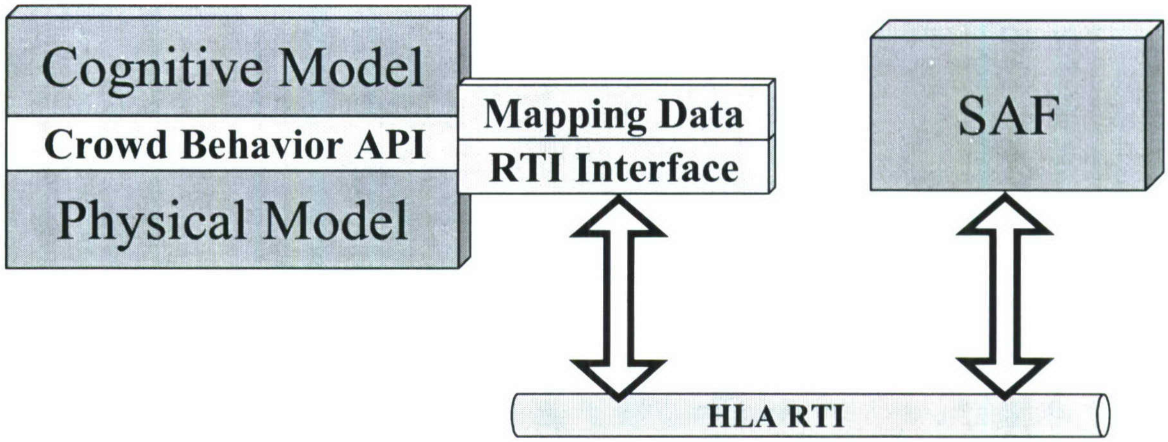

Figure 5. Generic crowd federate architecture.

6.3.2 Architecture approach

The Crowd Behavior API facilitates integration, communication, and interoperability of crowd cognitive models with crowd physical models. HLA compliance allows another level of interoperability that may be exploited. Physical models that are uniquely military oriented are immediately available with the use of the HLA. This combination of the Crowd Behavior API and HLA compliance allows for the development of a crowd federate architecture that may draw from the military as well as the entertainment industry to utilize the best of both worlds in carrying out realistic simulations of crowds in military scenarios.

The approach used in the design for the crowd federate is to start with a generalized API for an architecture that supports the reuse of existing cognitive models as well as existing physical models. The API is intended to facilitate control of the physical model by the cognitive model as well as event and state feedback from the physical model to the cognitive model. The API is illustrated below. It is thought that the API would also provide the access to the entity and interaction data needed by the RTI Interface. Figure 5 illustrates a generic crowd federate architecture and shows the Crowd Behavior API as a layer between the cognitive model and the physical model. This API facilitates the exchange of information between the two models tempered by the reconfigurable mapping data. Information about the crowd is exchanged across the RTI with other federates such as a SAF simulation.

In addition to refinement of the API through examination of background and current material, we conducted small experiments such as modifying force-ids of remote entities to emulate individuals in a crowd turning hostile. Other experiments include developing crowds using two levels of fidelity, controlling of entities using game API's in Maya and in the AI.implant software developers kit (SDK), and evaluating the development of a crowd simulation using simulation game engines. All these experiments are intended to flesh out the requirements for a Crowd Behavior API.

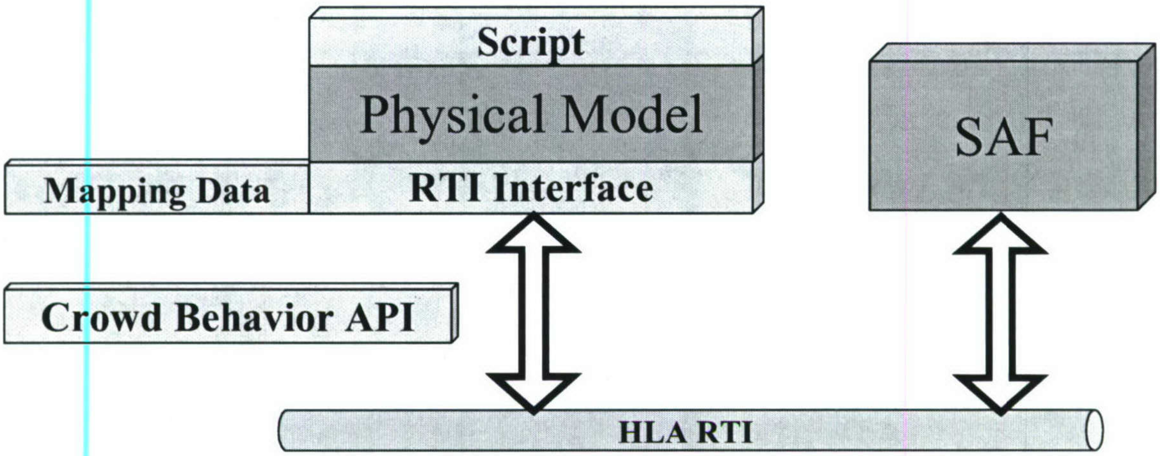

Figure 6. Implemented exploratory prototype crowd federate.

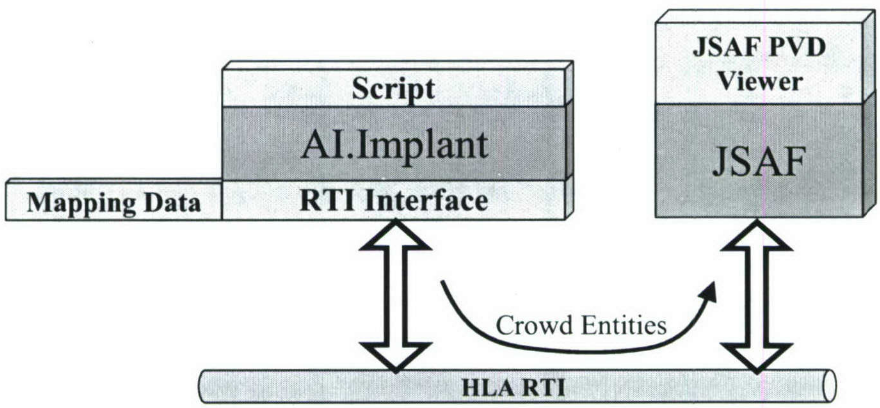

Figure 7. Running prototype.

The initial exploratory prototype implemented is shown in Figure 6. Note that the Crowd Behavior API, although implemented, was not integrated into the prototype. However, the prototype along with the various experiments aided in clarification of requirements for and refinements of the Crowd Behavior API.

The physical model used for this prototype was the AI.implant SDK while the SAF used was JSAF. In the prototype, characters in the crowd were registered with the HLA RTI and subscribed to by JSAF. The RTI objects representing the crowd characters were displayed on the JSAF plan view display (PVD) as remote entities. The prototype provided only one-way entity flow as illustrated in Figure 7. The generation of remote representations of JSAF military entities within AI.implant will be a follow on activity.

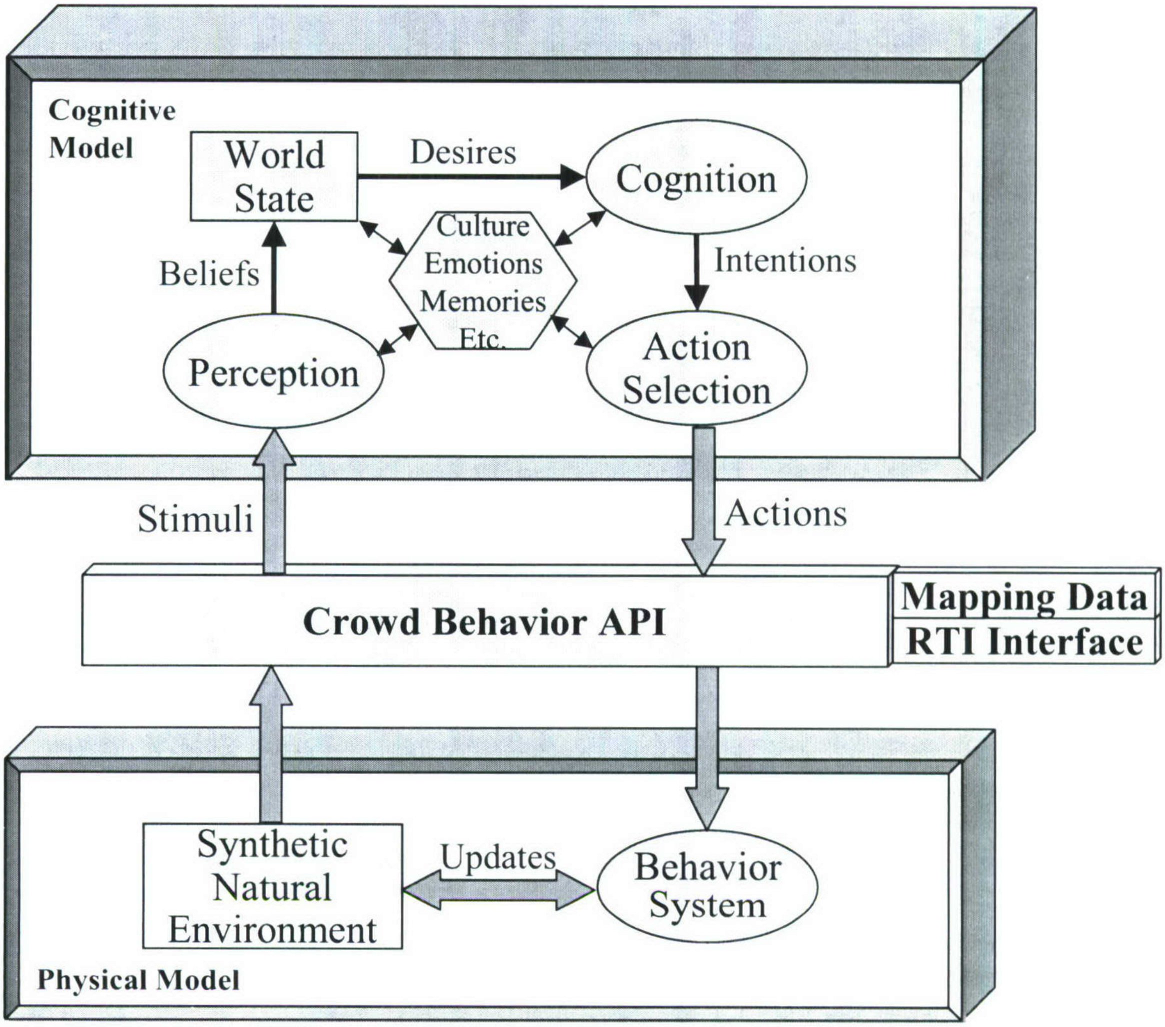

Figure 8. General cognitive and physical model designs.

6.3.3 Architecture design details

Details of the crowd federate are most apparent in the Crowd Behavior API. In Figure 8, general designs for the cognitive model and the physical model are shown. These designs are intended to represent functionality that may be mapped to any given specific cognitive or physical model. This is important since the Crowd Behavior API will support such functionality and, therefore, specifics of the API contain the framework necessary to convey functionality and information given the necessary set of mappings.

Shown in the design of the general cognitive model are the two main interfaces with the physical model and thus the API. These are the components that include perception and action selection. The API contains mechanisms to provide sensory data to the cognitive model so that this data may be perceived in the required manner. The API must also contain mechanisms to provide command and control to the cognitive layer over the physical layer. The converse is true with regard to the physical layer.

Attributes Category:
 External states => position, orientation, speed …
 Internal states => alive, anger, hungry …

Actions Category:
 Observation: see, hear, feel …
 Movement: stay, walk, run, flock with, follow path …
 Interaction: throw rock, shoot, talk …
 State change (callback): set attribute value

Figure 9. Example attributes and actions categories.

Sensor stimuli must be provided to the cognitive layer and actions provided by the cognitive layer must have a means to be executed. All this must occur via the Crowd Behavior API.

The specifications of the interface have been designed and refined based upon these general cognitive and physical designs derived from the crowd modeling literature, the implemented prototype, and the experiments conducted. Specific design criteria for the interface include the flexibility of the API to handle behavior transference from an individual influencing group behaviors or a group influencing an individual's behavior. Also of interest are individual or group behaviors that are influenced by triggers or persistent phenomena. It is believed but not proven that such capability is needed, as these are unanswered questions in the psych community. Whether or not these capabilities are needed in military simulations are questions we may be able to answer in surveying the military simulations community. Our intent is to provide the flexibility in the API to support the changing psychology of crowd behavior.

6.3.4 Human characters

Characters and groups of characters are defined by a set of attributes and set of actions to be carried out by these groups and the characters in the groups. These distinctions allow individual characters to carry out individualized actions while sharing actions designated to be group activities with members of its group. Figure 9 shows representative attributes and actions.

6.3.5 General command and control

The ability to perceive and affect the characters and their environment is provided through the execution of a predetermined set of crowd behavior actions that may be mapped to similar actions in the cognitive and physical models. It is believed that such a selection may be possible since this API is focused on the behaviors of crowds and there are reasonable sets of activities that are realistic for crowds to perform. Further, mappings of semantically exact actions, although desirable, may not be a necessary condition in that semantic differences should be small enough to be insignificant in the randomness of what it is to be human and unconstrained within the context of civilian life. This is of course based on the axiom that civilians are significantly more non-deterministic than military units, and therefore there is a wider range of believable behavior for crowds and the individuals within them.

```
A: Action functions can be initiated by action selection function
        ===> Need to be completed
        Movement: stay(CharID/GroupID), walk(CharID/GroupID, speed, orientation),
                  WanderAround(CharID/GroupID, <parameter list>),
                  AvoidObstacle(CharID/GroupID, <parameter list>), etc
        Observation: look(CharID/GroupID, orientation), etc
        Interaction: throwRock(CharID/GroupID, <parameter list>, etc

B: State change functions can be initiated by physical model
        State change (callback): SetAttri(CharID, Attrs[], Values[])

C: General functions that create and set characters, groups and actions
        ActionName <= CreatAction(ActionType, Parameters[]);
        CharID <= CreatChar(<Attrs[]>, <Actions[]>, <GroupID[]>);
        GroupType <= CreatGroupType(<Attrs[]>, <ActionNames[]>);
        CroupID <= CreateGroup(CroupType, <CharIDs[]>);

        Boolean <= AddAttr(CharID/GroupID/GroupType, Attrs[]);
        Boolean <= SetAttrValue(CharID/GroupID/GroupType, Attrs[], Values[]);
        Boolean <= DelAttr(CharID/GroupID/GroupType, Attrs[]);
        Boolean <= AddAction(CharID/GroupID/GroupType, <ActionNames[]>);
        Boolean <= DelAction(CharID/GroupID/GroupType, <ActionNames[]>);

        Boolean <= JoinGroup(CharID, GroupID);
        Boolean <= LeaveGroup(CharID, GroupID);
```

Figure 10. Sample API specifications.

Figure 10 shows example detailed specifications for controlling behavior and exchanging state information for human characters.

6.3.6 Character HLA interface

Mappings for exchange of information with other federates will depend upon the ability of the Federation Object Model (FOM) to support the necessary information. Initially, the Real-time Platform Reference Federation Object Model (RPR FOM) will be used to support interoperability with selected semi-automated forces (SAF) systems. It is believed that there will be a set of attributes and interactions that will not be supported by the RPR FOM nor any of the SAF systems. Such a set would remain part of the simulation object model (SOM) of the crowd federate unless and until the cognitive model portion of the crowd federate were to be executed on a separate node from the physical model portion of the crowd federate to in fact create a distributed crowd federate. In such a case, the RPR FOM would need to be augmented to support transfer of the extraneous set of data. The HLA interface therefore is a mapping dependent upon the FOM used.

6.4 Implementation experiments and results

Six implementation experiments were conducted to learn about potential problems and solutions in implementing a crowd federate. All of the experiments were designed to evaluate the ability of the Crowd Behavior API to support various configurations that might be necessary. Those experiments were:

1. Character modeling
2. Crowd fidelity modeling
3. Standalone CrowdFed
4. CrowdFed federation (includes testing JSAF support for crowds)
5. Game view CrowdFed
6. Terrain development processes for game technology interoperability

The following sections provide details of the experiments.

6.4.1 Implementation experiment: Character modeling

Objective. The objective in character modeling was to develop character models at varying levels of fidelity that could support close views of crowd participants as well as distant views of the whole crowd. Additionally, low-resolution models were needed to support large crowd animations.

Method. Initial development of a coarse human figure visual model tested performance within the AI.implant and Maya behavioral environment. Walking, climbing and interpolation motion animations were developed and converted to animation clips that could be called by AI.implant during a simulation. These incorporated lateral movement, e.g., during a walk cycle animation clip the figure walks from point A to point B; an animation methodology that utilizes Maya's ability to offset translation relatively. AI.implant however does not support this functionality so it was found that animations have to loop on the spot. A running 'on the spot' clip was developed and tested accordingly.

Next, a high-resolution human figure model constituting subdivision surface geometry was converted to polygonal geometry and its complexity reduced for real-time performance. Material properties were assigned to the figure for improved realism. To control the geometry and to prepare for animation the figure was rigged with an inverse kinematics skeleton. This included lattice deformations for bulging muscles/twisting upper body; pole vectors for elbow, shoulder and knee joints to prevent flipping during rotation and to constrain movement to the correct planes. The geometry was subsequently bound to the skeleton so that it would deform with the bones when these were animated. In particular, geometry points were assigned different deformation weightings to allow smooth deformations across the figure skin. AI.implant developed walking and running animation clips that looped in position for calling.

Results. Several character models were developed at varying levels of resolution. Polygon counts of the models range from over 10,000 down to 440 polygons. As expected the high polygon count characters could only support two to three characters in real-time rendering. Approximately fifty low polygon count characters could be easily supported in real-time. An example high-resolution model obtained from reference material is shown in Figure 11 on the left while a low-resolution model developed for this project is illustrated on the right.

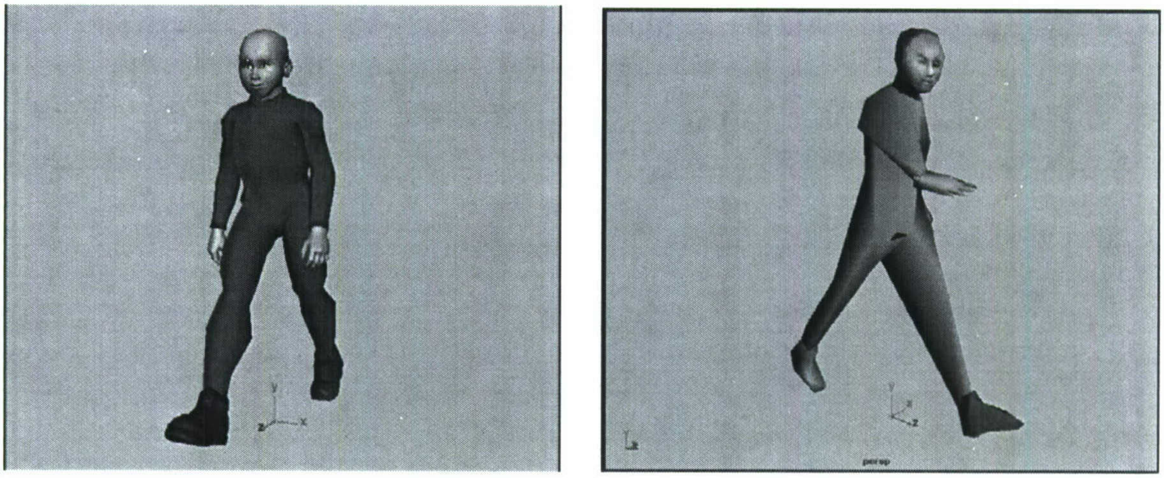

Figure 11. Comparison of higher- and lower-resolution human character visual models.

Conclusions. High-resolution models are difficult to work with in real-time rendering. However, for non real-time purposes, these high-resolution models can be rendered off-line and played back in real-time. It should be noted that these difficulties arose within the Maya environment. Using the AI.implant SDK, the numbers of characters that can be supported are much larger since rendering is processed separately and by a more optimized rendering engine.

6.4.2 Implementation experiment: Crowd fidelity levels

Objective. The objective was to examine two levels of crowd fidelity using AI.implant – one where the crowd is wandering around and the other where they have purposeful movement.

Method. Crowd fidelity modeling includes the development of scenario characters with varying resolution (polygon count), applying animation characteristics to the characters which includes providing a them with skeletons and specific movement clips, and incorporating them into the Maya environment where they are given AI.implant behaviors. The type of AI.implant behaviors they are given creates the level of crowd fidelity. For this experiment, AI.implant crowds were given the two levels of fidelity. The Quantico Combat Town terrain database, illustrated in Figure 12, was used as a virtual venue for the experiment.

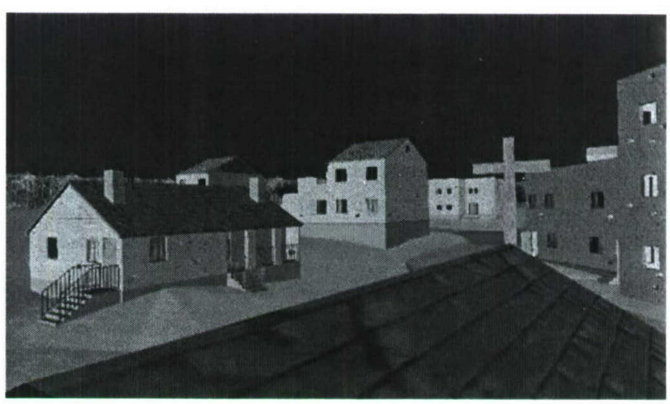

Figure 12. Quantico Combat Town terrain database.

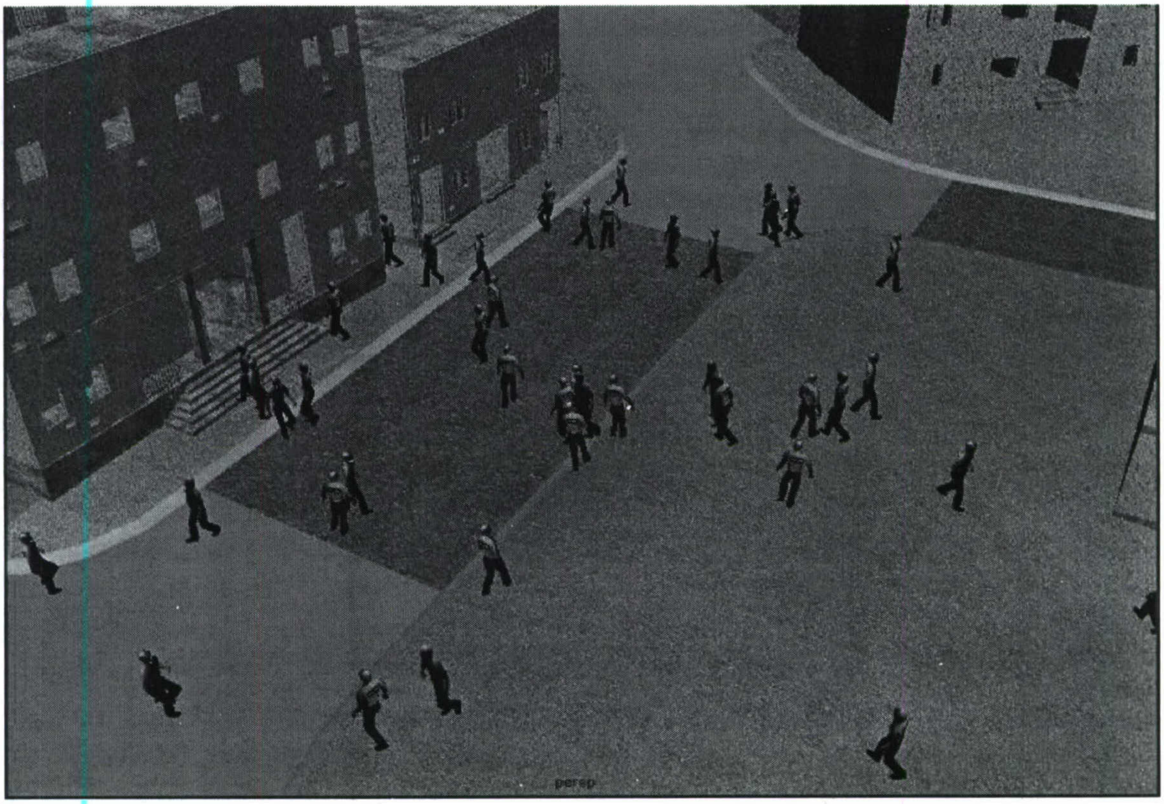

Figure 13. Lower fidelity crowd behavior.

Results. Two levels of behavior fidelity were studied. At fidelity level 1 (lower fidelity), people were wandering around. Figure 13[11] shows an image at low fidelity; in it, autonomous characters randomly moving around on the terrain and avoiding buildings automatically. The AI.implant behaviors used are "Wander Around" and "Avoid Barrier".

In contrast, Figure 14[12] shows an image at fidelity level 2 (higher fidelity); in it, the autonomous characters are flocking, wandering, following paths, and seeking. Several of them form groups and flock with each other. Some follow different paths as individuals. One character seeks an object in a building; when he gets there, he stops. The others as before just wander around. The AI.implant behaviors used are "Wander Around", "Avoid Barrier", "Flock With", "Follow Path", "Seek To", and "Avoid Obstacle".

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[11] Figure details: Maya scene file name: c:\Terrain\Crowdboy.mb; Reference file name: c:\mayas\boyPOlyWalking6Reduced.mb; Polygon count around 900; Good animation clip.

[12] Figure details: Maya scene file name: c:\Terrain\CrowTest2.mb; Reference file name: c:\mayas\Jwalk.mb; Polygon count "high"; Coarse animation clip.

Figure 14. Higher fidelity crowd behavior.

There were a number of issues encountered:

1. Increased numbers of the characters slows down the real-time rendering of the scene. This should not be a problem when the scene is taken out of Maya environment -- especially if we separate simulation and rendering into different processes.
2. The initial position of the characters is constrained. The autonomous characters are forced by AI.implant to stay at the origin of the scene. (This is not a problem identified in the AI.implant literature.)
3. Currently we have a limited number of animation clips. Different animation clips have to be carefully created to work with different moving speed of the characters.
4. Moving and facing a barrier can be unnatural. The steering forces drive the movement of the autonomous characters in AI.implant, which is determined based on their behaviors and surroundings. Multiple behaviors of a character and its surrounding objects will generate a combined steering force that may not be what we wanted. (This can be solved using the action selection mechanism in AI.implant.)
5. Currently we have not tested the action selection and sensor mechanisms. A decision tree needs to be carefully designed and more animation clips are needed.

Conclusions. Although we were able to successfully create two levels of crowd fidelity, many issues were encountered. These issues need to be explored further along with creating even higher fidelity purposeful movement through the use of decision trees.

6.4.3 Implementation experiment: Standalone CrowdFed

Objective. Create crowd behaviors outside of the Maya Environment.

Method. Standalone CrowdFed encompasses the ability to simulate the different fidelity crowds outside of the Maya environment. This means that the AI.implant SDK needed to be utilized.

Our first experiment creating simple objects and using simple behaviors was a success. A sphere with a bounding volume was created on flat AI.implant terrain and moved around using the AI.implant wandering behavior.

Follow on experiments recreate the low and high fidelity crowd models with only the AI.implant SDK. Crowds would wander around using information from the AI.implant "marked up" terrain used earlier within Maya.

Note that this configuration does not contain a viewer but when instantiated in a CrowdFed federation would create objects that would be viewed on participating federates with viewers such as JSAF.

Results. Crowds successfully created and executed outside of Maya using the AI.implant SDK. *Conclusions.* The AI.implant SDK is an advantageous method to use given the speed and flexibility achieved. Although the crowd is not visualized, these entities may be viewed on other displays when federated. However, to visualize the highest fidelity behaviors of crowd members, a visualization component needs to be added by way of a rendering engine.

6.4.4 Implementation experiment: CrowdFed federation

Objective. Civilian entities can be created to move amongst combating entities and supposedly not be harmed. These entities can then be made to become combative at which time they may be attacked by the fighting units.

Method. Civilian entities in a test federate were created and placed in the vicinity of military entities (M1A1 platoon). The civilian entities appear in JSAF as remote entities. The military entities were created within JSAF so they are local entities. The rules of engagement on these military entities were set to weapons free.

Remote civilians, with ForceIDs of neutral and friendly, were not shot at by the military entities. The neutral civilians were also placed within the context of a battle with military entities that were fighting (shooting each other). Again the civilian entities were not shot at.

As soon as the ForceIDs of some of the civilians were changed to enemy, those civilians with changed ForceIDs were shot. The other civilians with ForceIDs of neutral were untargeted.

This test federate was then integrated with AI.implant so that the civilians created were in fact crowd entities created within the AI.implant SDK but viewed on the JSAF PVD.

Results. The Test federate was integrated with AI.implant SDK to create an RTI compliant CrowdFed. CrowdFed non-combatant civilian entities viewed on JSAF changed their ForceIDs from neutral to enemy and were then attacked by friendly forces in JSAF. One issue encountered is that the conversion of position information is off by about a 100 meters. This may be due to the use of different geographical datum information between JSAF and the CrowdFed.

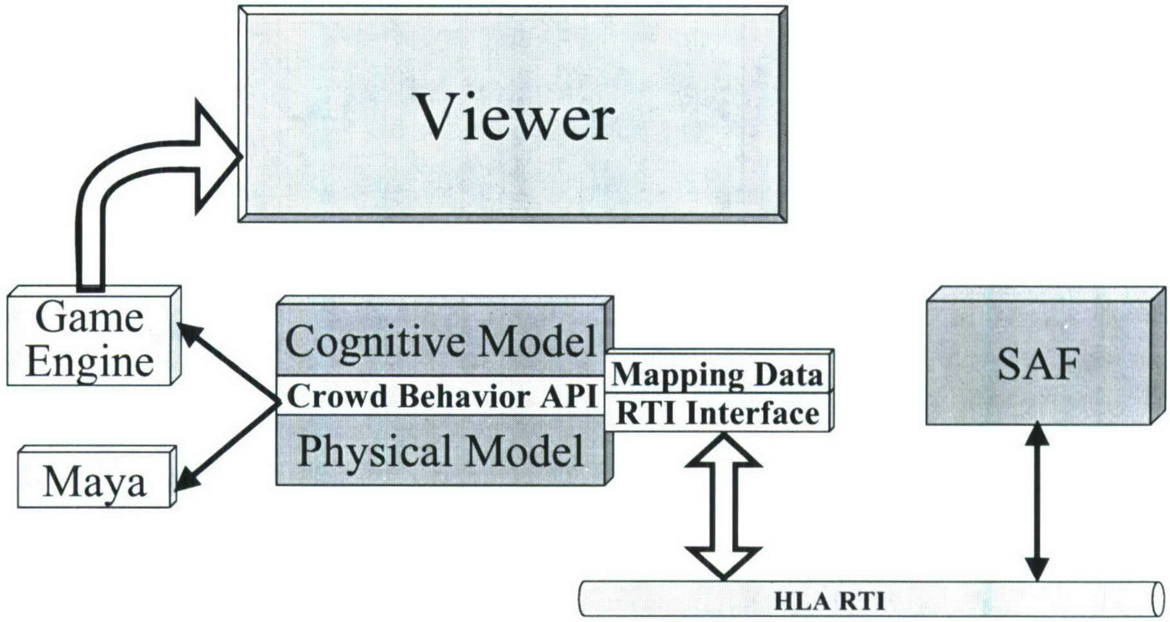

Figure 15. Game View CrowdFed architecture.

Conclusions. CrowdFed civilian crowd members can be viewed on JSAF and can change their ForceIDs to emulate neutral crowd members turning hostile. Individual members in the crowd can turn hostile while others remain neutral. Friendly forces can then target the hostiles but not the neutrals within the crowd. However, it is unclear whether the neutral crowd members can obscure line of sight (i.e., provide cover and concealment).

Allowing for the detection of JSAF entities in AI.implant is task yet to be undertaken. However, it will be addressed in follow-on efforts.

6.4.5 Implementation experiment: Game view CrowdFed

Objective. As mentioned previously, to visualize the highest fidelity behaviors of crowd members, a visualization component needs to be added by way of a rendering engine. The objective is to view CrowdFed entities along with JSAF entities in real-time using the AI.implant SDK along with either the RenderWare or Intrinsic game engine.

Method. The architecture is shown Figure 15. The architecture shows the AI.implant SDK accessing graphical models generated using Maya for use as entities in the scenario. Then AI.implant provides state information to the Game Engine that renders the scenario on a chosen platform/viewer (PC, Xbox, etc.). This visualization would provide valuable insight into what the crowd is doing and sensing so that the scenario can be more easily validated.

Results. The experiment is still ongoing as this is written.

Conclusions. The experiment is still ongoing as this is written.

6.4.6 Implementation experiment: Terrain development for game interoperability

Objective. The objective here is to document the process involved with the development and correlation of terrain databases used in military simulation with those employed in game simulations. This process was documented during the creation of an urban environment for the Somalia CTDB terrain.

Method. In order to integrate buildings into the Somalia CTDB dataset we used DART from TERREX. By using DART we were able to re-use existing CTDB data. DART was used to import the CTDB dataset into TERRAVISTA, another product from TERREX. Once in TERRAVISTA we were able to generate a 3D terrain database in OpenFlight format. This database then can be populated with buildings and geo-referenced satellite imaging.

While pursuing this effort we encountered that the CTDB database only had the terrain information, but no vector data that could indicate the presence of buildings, roads, rivers, bridges, power lines, etc…

We identified a satellite imaging service that provides the georeferences datasets at a cost of $1,100 for the particular area of interest which is Mogadishu, Somalia (Figure 16). This dataset was not included in the generation of the new dataset, instead less accurate but freely available datasets where used.

The buildings were extracted from a video game called Black Hawk Down from Novalogic. Two pieces of software were used for obtaining the models in a format that could be transferred into the CTDB database. The first software is called PFFextractor which was used to extract the compressed data format used by this gaming company. This extraction utility obtains the 3D models in 3DI format which is a proprietary 3D object file format, as well as the texture maps. Once the 3DI files are extracted, a software called Ultimate Unwrap3D is used to convert the 3DI graphics format into a 3DS file format that then can be imported into Multigen Creator in order to generate an OpenFlight file that can be used inside TERRAVISTA for the CTDB database generation.

Once the OpenFlight buildings are generated, they are imported into TERRAVISTA to be placed in the Somalia database. Once the file is imported, new vector files are created as point features in the terrain, which contain the building models extracted from the game. Because we used freely available unreferenced satellite images and 3d objects, the building data imported is not accurately placed in the geo-referenced terrain (Figure 17). Once the buildings have been placed in the terrain then we export the TERRAVISTA dataset as CTDB by generating both .c7b and .c7l file formats that can then be used in a SAF application.

Figure 16. Satellite image of Mogadishu Somalia.

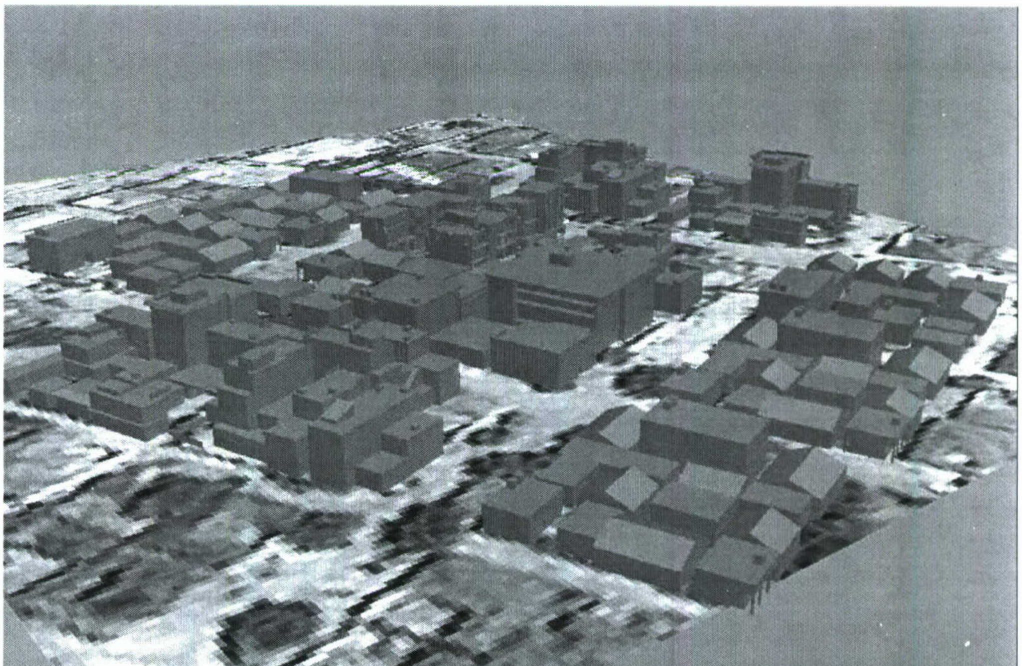

Figure 17. Mogadishu dataset with imagery and ungeoreferenced buildings.

Results. Two CTDB datasets of Somalia are available. The original that contains no features and one created with ungeoreferenced Mogadishu buildings. Additionally, terrain datasets correlated to these were created for Maya.

Conclusions. Terrain generation and correlation of needed geographical regions is not a simple task. Legacy databases should be reused where appropriate. However, the process is tenable, as we have demonstrated.

6.5 Design study findings

We were able to mitigate COTS/GOTS integration risk as well as terrain correlation risk by successfully implementing the crowd federate exploratory prototype. Additionally, an enhanced understanding and refinement of the Crowd Behavior API requirements was achieved. Many of the issues discussed above are resolvable and will be addressed in follow-on efforts.

Also of interest is the significant level of flexibility found in COTS entertainment industry tools such as AI.implant. With these tools, civilian/crowd behavior is easily created in a believable and high fidelity manner, where as, military behaviors are not easily available in realistic fashion in these tools. There is a realization that military simulations model military behaviors well while tools from the entertainment industry model other behaviors well. The combination of the two seems to bring the best of both worlds together in the creation of a federate for representing civilian crowds in military scenarios.

7. Conclusions

This section summarizes the findings of this report and recommends further related research and development.

7.1 Summary of findings

An adaptation of a previously proposed requirements analysis method was applied to identify crowd modeling requirements and relate them to uses of military simulation. A large number of crowd modeling requirements were found; these requirements included needed crowd behaviors, military missions affected by crowds, and crowd effects to model. The identified requirements should provide a good basis for implementing a useful crowd simulation. The primary finding of the requirements analysis was that because of the requirements' diversity in scope and intent, no single crowd behavior model is likely to satisfy all of the requirements. Therefore, research and development efforts aimed at developing a crowd model should be explicitly oriented towards its intended uses and the requirements associated with those uses.

There are many variables that may influence crowd behavior. Few existing models of crowd behavior have strong underpinnings in psychology. An area of psychological research that seems particularly relevant to crowd behavior and lacking in much of the existing research is cognitive psychology. Improving measurement of cognition and behaviors is essential for determining probabilities of behavioral consequences. At issue is the level of situational specificity with which each is measured. Research suggests that models of crowd members' behavior should consider past experiences and implications for future outcomes. In addition to the psychological factors, situational factors may also influence the cognition-behavior relationship, such as the presence of an audience or the affect of attention on self-presentational concerns. Future research on crowd behavior during military operations should address these more challenging areas of cognitive psychology. Furthermore, cultural differences must also be modeled because American soldiers are increasingly faced with behaviors, such as the use of human shields, which they are unfamiliar with.

Module integration risk and terrain correlation risk in an eventual crowd federate were both mitigated by successfully implementing the crowd federate exploratory prototype. The implementation experiments identified possible problems and solutions in federate development. An understanding of how to implement a Crowd Behavior API was achieved. Also of interest was the significant level of flexibility found in COTS entertainment industry tools, such as AI.implant. With these tools, civilian/crowd behavior can be created in a believable and high fidelity manner with reduced difficulty. There is a realization that military simulations model military behaviors well while tools from the entertainment industry model other behaviors well. The combination of the two seems to bring the best of both worlds together in the creation of a federate for representing civilian crowds in military scenarios.

7.2 Future work

As a result of the study documented in this report, we have formulated several research questions regarding crowd modeling, which are listed here:

1. *Crowd model types.* What types of crowd models have or can be developed, and which types are best suited for different applications and levels of resolution in military simulation?
2. *Crowd simulation architecture.* Is there a simulation software architecture that could serve as a reconfigurable support structure for developing and testing multiple crowd models?
3. *Behavior fidelity requirements.* How large a repertoire of crowd behaviors, and how much fidelity in those behaviors, is needed for different intended uses?
4. *Cognitive model requirements.* Are cognitive models of the reasoning and emotional states of individual crowd members needed to generate realistic crowd behavior, and how much detail must those models have?
5. *Psychological model applicability.* Can current psychological models of crowd behavior, which are sometimes descriptive and qualitative, be adapted to serve as the basis for quantitative computational models of crowd behavior suitable for implementation as software in the context of a simulation?
6. *Crowds as civilians.* Is there a difference between crowd behaviors and more general civilian/non-combatant behaviors, and if so, which of the crowd/civilian behaviors are required in military simulation?
7. *Control vs. emergence.* Should the behaviors of crowds, which are made up of individuals, be modeled using methods that depend on representing the state or controlling the behavior of the crowd at an overall level, or instead using methods that model only individual behavior and allow crowd behaviors to emerge from the individuals' cumulative actions?

We recommend a follow-on project to actually develop and test a crowd federate, based on the lessons learned in this project. The scope of the recommended research and development is crowd behavior modeling for military and para-military scenarios. It would focus on modeling crowd members at the individual level, rather than the aggregate level, in the context of simulations that model military combatants and other scenario participants at the individual level. To some extent, the project would focus on the training and experimentation applications, though this is primarily a reflection of degree of validation; with additional validation effort the capabilities we recommend developing could be applied to the more demanding analysis and acquisition applications as well.

The recommended research and development program has two objectives. The first objective is to design, implement, and test a multi-layered reconfigurable software architecture for a crowd federate, i.e., an HLA-compliant simulation that models crowd behavior. The crowd federate architecture would be in the form of a usable crowd federate that models crowd behavior in the context of a real-time, individual combatant-level simulation federation and includes initial models of crowd member cognition and of crowd member physical actions. The second objective is to use the crowd federate and federation to conduct two experiments. Those experiments will investigate crowd behavior fidelity requirements and assess the reconfigurability of the crowd federate architecture.

8. Appendices

The appendices include a list of references, a list of acronyms and abbreviations, sources for the requirements analysis, and brief biographies of the authors.

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8.2 Acronyms and abbreviations

Acronyms and abbreviations used in this report are listed and defined here. A much more complete list of military acronyms and abbreviations is available [DOD, 2001].

ACR	Advanced Concepts and Requirements
API	Application Programming Interface
AFRL	Air Force Research Laboratory
COTS	Commercial-Off-The-Shelf
DISAF	Dismounted Infantry Semi-Automated Forces
DMSO	Defense Modeling and Simulation Office
DOD	Department of Defense
GOTS	Government-Off-The-Shelf
FOM	Federation Object Model
HLA	High Level Architecture
JFCOM	Joint Forces Command
JCATS	Joint Conflict and Tactical Simulation
JTC	Joint Training Confederation
JTLS	Joint Theater Level Simulation
LLNL	Lawrence Livermore National Laboratory
M&S	Modeling and Simulation
MOOTW	Military Operations Other Than War
MOUT	Military Operations in Urban Terrain
NEO	Noncombatant Evacuation Operations
No.	Number
ODU	Old Dominion University
ODURF	Old Dominion University Research Foundation
ONR	Office of Naval Research
PVD	Plan View Display
R&D	Research and Development
RDA	Research, Development, and Acquisition
RPR FOM	Real-time Platform Reference Federation Object Model
RTI	Run-Time Infrastructure
SAF	Semi-Automated Forces
SBA	Simulation Based acquisition
SDK	Software Developers Kit
SOM	Simulation Object Model
TEMO	Training, Exercise, and Military Operations
U. S.	United States
VMASC	Virginia Modeling, Analysis, and Simulation Center
Vol.	Volume

8.3 Requirements analysis sources

A subset of the experts who provided input during the requirements analysis process gave permission to be identified as sources and provided biographies. They are listed in alphabetical order.

Michael Page Bailey was born in Baltimore, Maryland on May 19, 1961. He graduated from the University of North Carolina at Chapel Hill with a Ph.D in Operations Research in 1988, and became an Assistant Professor of Operations Research at the Naval Postgraduate School in Monterey, California. He was promoted to Associate Professor in 1993 and tenured in 1994. In 1995, he spent a sabbatical at the Office of the Chief of Naval Operations, Assessments Division, OPNAV-N81 as a visiting scholar. There he served as operations analyst in support of the Quadrennial Defense Review until 1997, whereupon he joined the Marine Corps as Principal Analyst, Modeling and Simulation. In December 1999, he joined the Marine Corps' Training and Education Command as Technical Director. In December 2000, the Marine Corps formed the Training and Education Technology Division, with Dr. Bailey as its head. Technology Division is responsible for requirements, policies, and sponsorship of all technology applicable to Marine Corps individual training, unit training, exercises, and ranges.

Michael Ferguson is currently a Visiting Professor of Wargaming and Simulation at the Joint Forces Staff College. Previously, he was a career Marine Corps Officer and served in Northern Iraq (Operation Provide Comfort) and Somalia (Operations Restore and Continue Hope). He was also assigned to the Joint Warfighting Center as an Exercise Modeling and Simulation Planner. He has a Masters of Science degree from the Naval Postgraduate School in Operations Research and Systems Analysis.

John A. Sokolowski is a Senior Scientist at Old Dominion University's Virginia Modeling, Analysis & Simulation Center. He holds a B.S. in Computer Science from Purdue University, a Master of Engineering Management from Old Dominion University (ODU), and a Ph.D. in Modeling and Simulation program from ODU. Prior to coming to VMASC, he spent 27 years in the Navy as a submarine officer, retiring at the rank of Captain. His final Navy assignment was as Head, Modeling and Simulation Division, Joint Warfighting Center, U.S. Joint Forces Command, where he was responsible for providing joint and command staff training using simulation systems. Dr. Sokolowski's research interests include human behavior modeling and multi-agent system simulation.

8.4 Authors' biographies

The authors' biographies are given in alphabetical order.

Ryland C. Gaskins III received his Ph.D. in Human Factors and Masters in Industrial Organizational Psychology from George Mason University. Since joining the ODU faculty, he has taught both graduate and undergraduate courses in Human Factors, Industrial/Organizational Psychology, Research Methods, Personnel Psychology, Organizational Psychology, Ethics and Introductory Psychology. Dr. Gaskins' research interests are in the area of training and simulation, virtual environments, macroergonomics, persuasive computing, human abilities and task characteristics measurement for selection and placement. His favorite past time is cruising and exploring the Chesapeake Bay onboard his sailboat, Panacea. Dr. Gaskins is originally from Kilmarnock, Virginia and currently resides in Virginia Beach.

Frederic (Rick) D. McKenzie is an Assistant Professor of Electrical and Computer Engineering in the College of Engineering and Technology of Old Dominion University (ODU). Prior to joining ODU, Dr. McKenzie held a senior scientist position at Science Applications International Corporation (SAIC), serving as Principal Investigator for several research and development projects. While at SAIC he was a Team Lead on a simulation system that encompassed the training requirements of all military services and joint operations. He has had several years of research and development experience in the software and artificial intelligence fields, including object oriented design in C++, LISP, and knowledge-based systems. Dr. McKenzie has also had two years teaching experience in artificial intelligence, software languages, and data structures. Both his Masters and Ph.D. work were in artificial intelligence, focusing on knowledge representation and model-based diagnostic reasoning. He received a Ph.D. in Computer Engineering from the University of Central Florida in 1994.

Mikel D. Petty is Chief Scientist of the Virginia Modeling, Analysis and Simulation Center at Old Dominion University. He received a Ph.D. from the University of Central Florida (UCF) in 1997, a M.S. from UCF in 1988, and a B.S. from the California State University, Sacramento, in 1980, all in Computer Science. Dr. Petty has worked in modeling and simulation since 1990 in the areas of simulation interoperability, computer generated forces, multi-resolution simulation, and applications of theory to simulation. Since 1990 he has published over 90 research papers and has been awarded over 30 research contracts. He previously worked for the Institute for Simulation and Training at the University of Central Florida. He has served a member of a National Research Council committee on modeling and simulation and is currently an editor of the journal *SIMULATION: Transactions of the Society for Modeling and Simulation International.*